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Status and ecology of the brown pelican in the Greater Puerto Rican Bank region

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STATUS AND ECOLOGY OF THE BROWN PELICAN IN THE GREATER PUERTO RICAN BANK REGION

Iowa State University PH.D. 1985

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Status and ecology of the brown pelican in the Greater Puerto Rican Bank region

by

Jaime Agustin Collazo

A Dissertation Submitted to the
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Iowa State University
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INTRODUCTION

The brown pelican (Pelecanus occidentalis) has been listed as an endangered species throughout its entire range (U.S. Fish and Wildlife Service, 1979). This status designation includes three subspecies occurring in the United States, Puerto Rico, and the United States Virgin Islands (Wetmore, 1945). The range of Pelecanus occidentalis carolinensis extends from North Carolina along the Atlantic Coast south to Florida and the Gulf Coast States. On the western coast, P. o. californicus occurs along the entire Pacific Coast of the United States and Mexico. P. o. occidentalis occurs throughout the Caribbean islands, including Puerto Rico and the U.S. Virgin Islands (American Ornithologists' Union, 1983).

The continental populations have received a great deal of attention by researchers in the recent past. Widespread reproductive failures occurred in breeding populations in Texas, Louisiana, South Carolina, and California from the 1950s through the early 1970s (Anderson and Hickey, 1970; Schreiber and Risebrough, 1972; Blus et al., 1974b; Anderson et al., 1975; and others). By the late 1960s, pelican populations on the Texas-Louisiana coasts had been extirpated, and productivity elsewhere remained dangerously low.

The major cause of endangerment was chlorinated pesticides, particularly DDE and other DDT metabolites

(Anderson and Hickey, 1970; Blus et al., 1971; Schreiber and Risebrough, 1972; Blus et al., 1974a). These pesticides reduced eggshell thickness with concomitant reduction in reproductive success (Blus, 1970; Risebrough et al., 1971; Blus et al., 1972; Blus et al., 1974b). Other factors adversely affecting the reproductive success of brown pelicans were human disturbance, disease, inclement weather, heavy infestation of ticks, and unpredictable food availability (Blus, 1970; King et al., 1977a, 1977b; Schreiber, 1979; Anderson et al., 1982; Anderson and Gress, 1983). None of these factors, though, equaled the detrimental effects of organochlorine pesticides which brought the species to a precarious situation in many areas of its range.

Since the late 1970s, the pelican populations along the eastern coast of the United States have staged a strong resurgence (Mendenhall and Prouty, 1978; Schreiber, 1979, 1980a; Schreiber and Schreiber, 1983). Re-introduction efforts in Louisiana have resulted in the establishment of a small breeding population (Nesbitt et al., 1978; Blus et al., 1979). In California, pesticide levels have decreased in eggs, and reproductive success has improved (Anderson and Gress, 1983). These encouraging trends are coincident with the discontinued use of DDT in the United States and strict conservation measures implemented by Federal and state agencies. The steady recovery of the eastern brown pelican

populations now seems to be assured with the recent implementation of a recovery plan (Williams et al., 1979) and the apparently stable Atlantic Coast populations.

Given the strength with which the Atlantic Coast populations have recovered (Schreiber, 1980a), populations occurring in Alabama, Florida, Georgia, South Carolina, North Carolina, and points northward along the Atlantic Coast have been removed from the U.S. Fish and Wildlife Service's list of Endangered and Threatened Species (U.S. Fish and Wildlife Service, 1985). However, the endangered status designation of the species was not changed in other regions.

In spite of all of the research and conservation efforts in the continental United States, Caribbean populations were poorly known and studied (Schreiber and Risebrough, 1972). However, endangered status was extended to include Caribbean pelicans and protective measures were implemented. These were ad hoc measures and were not based on well-documented data.

For Puerto Rico, the species has been listed as a resident species since the last century (Gundlach, 1878; Cory, 1892). Gundlach (1878) reported that pelicans bred from February through September although no site was indicated. Wetmore (1916) indicated that pelicans were common in the coastal regions of Puerto Rico but not on Mona and Desecheo islands off the western coast of Puerto Rico. Danforth (1931) reported that 40 pairs nested on Enrique Cay from 2 April

through 15 August 1927 in the Parguera area in southwestern Puerto Rico. Another breeding colony on Turrumote Cay in the same general area has been traditionally mentioned in the literature (Perez-Rivera, 1979). However, the mislabeling of cays has been a problem in identifying historical nesting sites.

In subsequent visits to some offshore islands, Danforth (1935, 1937) found no evidence of nesting activity on Culebra and Vieques. More recently, Erdman (1967) reported seeing nestlings in a colony at Cayo Frios in Montalva Bay east of the Parguera area in the late 1950s. Biaggi (1970, 1974, 1983) indicated that pelicans were common around Puerto Rico and that nesting probably occurred from April to September but did not indicate where. Sorrie (1975) and Kepler and Kepler (1977) commented briefly on the activities and numbers of pelicans on Vieques and Culebra Islands, respectively. However, Sorrie (1975) noted that Kepler had discovered a nesting colony on a cay (Conejo) off the southeastern coast of Vieques, 20 July 1971.

In 1977, the Department of Natural Resources of Puerto Rico became concerned over the possibility that environmental pollutants, as on the mainland, were adversely affecting pelican populations on the island. It was concluded that more intensive studies needed to be conducted to properly evaluate the status of pelicans in Puerto Rico. Perez-Rivera (1979),

on the other hand, contended that pelican populations in Puerto Rico were in a "healthy condition" and recommended that the species be removed from the endangered list. To support his contention, Perez-Rivera reviewed data on the numbers of pelicans seen by him and other biologists at various localities around the island. These numbers ranged from 25 to 125 individuals. Raffaele (1983) did not list the species as endangered and indicated that nesting colonies were located near Parguera, Anasco Bay, and Conejo Cay, Vieques.

The most recent attempt to evaluate the status of pelicans in Puerto Rico and offshore islands was conducted by Schreiber et al. (1981). The nesting colony on Conejo Cay, near Vieques Island, was monitored for 8 months in 1978. They reported that pelican numbers on Vieques Island fluctuated between 200 and 250, and that the population was healthy and reproducing. They also suggested the need for a longer-term study of the biology of the species in this part of its range.

Similarly, there is little information available on pelicans for the U.S. Virgin Islands. Cory (1892) listed the species as a resident. Danforth (1930) reported that pelicans occurred in every "suitable" locality around the islands but noted that the numbers never exceeded 25 at any given locality. Beatty (1930) also reported that pelicans were common residents and nested in February and March on St. Croix and on Buck Island. In a later trip in December to the St.

Thomas-St. John area, Danforth (1935) found no evidence of nesting. He noted, however, that up to 300 individuals could be seen on Great Thatch and Jost Van Dyke, islands under British jurisdiction. Nichols (1943) collected eggs from a nesting colony on Dutch Cap Key in mid-April 1943. Seaman (1958) reported pelicans nesting on Whistling Key off St. John and suggested that nesting also probably occurred on Mary Point, St. John. Robertson (1962) counted 80 individuals on St. John. Subsequently, Robertson and Ogden (1969) discovered a "thriving" nesting colony of at least 500 individuals including juveniles and attending adults in September 1969 off St. John. The colony was probably Congo Cay.

More recently, Philibosian and Yntema (1977) listed the pelican as endangered. Raffaele (1983), on the other hand, reported nesting colonies present on St. Croix, Buck Island, Congo Cay, Dutch Cap Key, Whistling Key, and Little Tobago but made no mention of their status.

In 1980, I initiated a three-year study of the ecology of brown pelicans in Puerto Rico and neighboring U.S. Virgin Islands in an attempt to provide the needed baseline information to adequately evaluate the status of the species in this region. The study was intended to: 1) determine numbers, distribution, and movement patterns; 2) identify prey species and assess the availability and abundance of prey; 3) describe habitat characteristics of both roosting and nesting

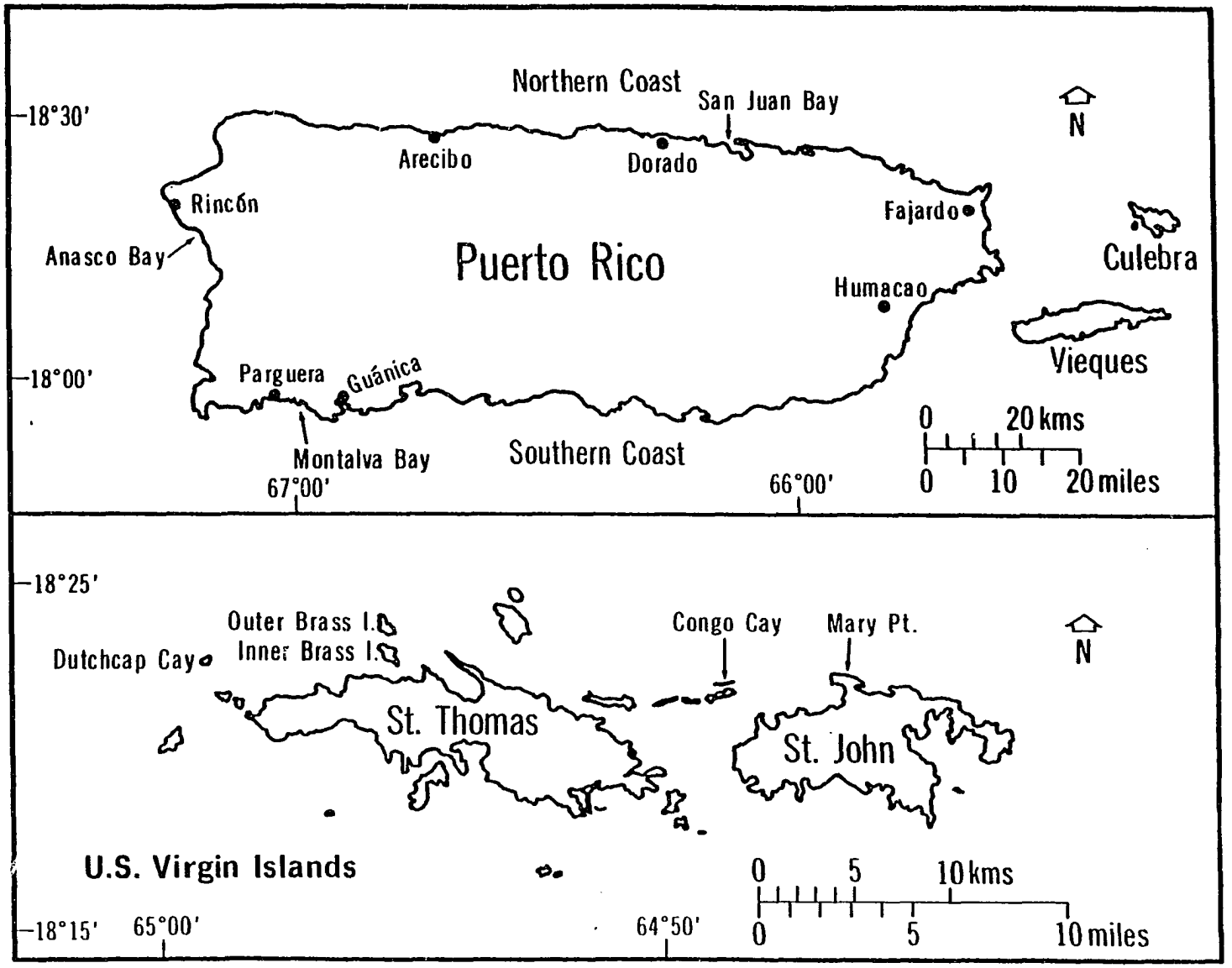
sites; 4) determine the timing and success of nesting; 5) estimate pesticide residue levels; and 6) assess the potential detrimental effects posed by human disturbance and the proximity of pollution sources to nesting colonies.

STUDY AREA

The study area consisted of the coastal zone of Puerto Rico and adjacent islands, and cays in the vicinity of St. Thomas and St. John in the United States Virgin Islands (Figure 1). Puerto Rico, its outlying islands, the U.S. Virgin Islands, and the British Virgin Islands are situated on the same geologic shelf known as the Puerto Rican Bank (Heatwole et al., 1981). Prevailing winds in this region are northeasterly. Marine currents tend to move east to west, although a northward current exists between Mona Island and Puerto Rico, and there is a northward deflection between Vieques and Puerto Rico (Kaye, 1959).

Generally, the coastal zone of Puerto Rico can be divided in two asymmetrical parts in terms of oceanic and physical features. The northern coast is characterized by strong wave action of the Atlantic Ocean, particularly during late fall and winter. The high energy wave action and winds have profound effects on the associated ecosystems (Cintron et al., 1978, Martinez et al., 1979). The southern half, on the other hand, is typified by calmer seas, the presence of extensive protective coral reef barriers, and a broader, shallower sand terrace. Well-protected bays, bordered by fringe mangroves, are common. In addition, a high percentage of the shallow sand terrace is covered by seagrass beds of Thalassia. Certain portions of the southern coast of Culebra,

Fig. 1. Map of Puerto Rico and the U.S. Virgin Islands showing important localities in the study area, 1980-1983.


Northern Coast
San Juan Bay
18°30'
Arecibo
Dorado
N
Rincón
Fajardo
Anasco Bay
Puerto Rico
Culebra
Humacao
Vieques
18°00'
Parguera
Guánica
Montalva Bay
Southern Coast
0 20 kms
0 10 20 miles
67°00'
66°00'
18°25'
Outer Brass I.
Inner Brass I.
Dutchcap Cay
Congo Cay
Mary Pt.
N
St. Thomas
St. John
U.S. Virgin Islands
0 5 10 kms
0 5 10 miles
18°15'
65°00'
64°50'

the southern, southwestern, and portions of the western coast of Vieques share similar characteristics.

The Virgin Islands also have a number of these "protected" sites concentrated mainly on the southern coasts or in areas where offshore cays serve as barriers to ocean currents. Many of these sites, however, have been altered by human habitation. As in Puerto Rico, the northern coastal zones exposed to the Atlantic Ocean tend to be deeper and subject to high energy oceanic currents.

Gazetteer

Sampling efforts and observations were concentrated in several localities described below:

Anasco Beach — This locality, the site of a nesting colony, 1980-1983, is on the western coast of Puerto Rico, near the town of Anasco and 4 km north of the mouth of Rio Grande de Anasco.

Arecibo Bay — This small bay with port facilities, partly exposed to ocean currents is on the north-central coast of Puerto Rico. It was an important feeding area for brown pelicans during winter, 1980.

Congo Cay — Located about 4.8 km west of Mary Point, St. John, U.S. Virgin Islands, this island has an area of about 0.5 km^2 and was the site of an important nesting colony.

Culebra Island Located about 27 km east of Puerto Rico, this large island of about 63 km^2 has mangrove forests on the southern coast with numerous bays, islets, and cays. It was a moderately important feeding and roosting area for pelicans.

Dorado lagoons One natural lagoon (Mata Redonda) and nine artificial ponds are on golf courses at the Dorado Beach and Cerromar hotels located on the north-central coast of Puerto Rico between Arecibo and San Juan Bays. It was an important feeding area for pelicans year-round.

Dutch Cap Cay This cay has an area of about 0.6 km^2 and is located about 3.6 km northwest of Botany Bay, St. Thomas, U.S. Virgin Islands. It was the site of the largest breeding colony in the Puerto Rico-U.S. Virgin Islands region.

Guanica Bay This is an open bay with small port facilities on the southwestern coast of Puerto Rico covering an area of about 4.5 km^2. A small nesting colony was discovered in this bay in 1981.

Humacao lagoons Located on the southeastern coast of Puerto Rico, this area is comprised of the Mandri Lagoon complex and adjacent Santa Teresa Lagoon. It was an important feeding area for pelicans year-round.

Jobos Bay The bay, located on the southern coast of Puerto Rico, and surrounding vegetation cover an area of about

110 km^2. It is the second largest estuary in Puerto Rico and was seasonally important as a pelican roosting and feeding area.

Mary Point This is a mushroom-shaped peninsula on the northern coast of St. John, U.S. Virgin Islands. It was the site of a small nesting colony.

Parguera This large reef-protected area with over 50 islets and cays extends for 16 km from Montalva Bay to Boqueron State Forest (Pitahaya) along the southwestern coast of Puerto Rico. Montalva Bay was the site of an important nesting colony. The entire area was considered an important feeding and roosting area for pelicans.

San Juan Bay This is a large, well-protected bay with large port facilities located on the northeastern coast of Puerto Rico. It was an important feeding and roosting area year-round.

Torrecillas and Pinones Lagoons These are natural lagoons bordered on the northwest side by Luis Munoz Marin International Airport and connected to the ocean by a canal. They are located about 11 km east of San Juan Bay and were a moderately important feeding and roosting area.

Vieques Island This large island, about 9.6 km off the southeastern coast of Puerto Rico, covers an area of about 83 km^2. The southern coast has numerous bays

bordered by fringe mangrove. A nesting colony was located on Conejo Cay about 1.7 km southeast of Cerro Matias.

Whistling Key A small cay located about 400 m west of Mary Point, St. John, U.S. Virgin Islands. It was the site of a nesting colony.

METHODS

Population Surveys

Pelican numbers for Puerto Rico and adjacent islands were estimated by periodic surveys taken from the air and at certain localities from a boat.

Aerial surveys were conducted on a quarterly basis and covered all the coastal zone of Puerto Rico and adjacent islands. Counts began at 0700-0800 and concluded at 1630. Flight altitude was 30 to 60 meters. The right-side door of a Cessna 172 was removed prior to all flights to insure maximum visibility. All pelicans seen along the shoreline were counted by two observers seated on the right side of the airplane. A third observer, seated behind the pilot, counted all the pelicans seen on the left (seaward) side. When surveying around a cay, the observers on the right side did all the counting. Upon encountering a flock of pelicans, the pilot was instructed to fly in circles above the flock until the right side observers agreed on the numbers counted. When flocks exceeded 75 individuals, black and white photos were taken to verify counts. Surveys of Mona Island and Desecheo Island were discontinued after four flights because only one or no pelicans were seen per count and coverage of these islands was time consuming.

The Torrecillas, Pinones, and Dorado lagoons were not sampled from the air because of air space restrictions. These

areas were surveyed by boat on the same day the aerial survey was conducted, and the counts were added to the aerial counts to obtain a grand total.

In addition to quarterly surveys, boat counts were conducted between 0630-1000 on San Juan Bay, Torrecillas Lagoon, Culebra Island, Humacao lagoons, Parguera area, Arecibo Bay, and Dorado lagoons. Routes were established so as to avoid overlap and possible count duplication. When possible, these counts were repeated monthly. At least two observers were present on each count.

During boat counts, the age composition of pelicans was determined, and differences in plumage coloration were noted following the age-plumage classification proposed by Blus and Keahey (1978). Binoculars (10 x 40) and a zoom spotting scope (15-60x) were used to ascertain plumage differences. Paired t-tests were used to detect differences between the number of adults and juveniles at any given locality.

Movement patterns were studied by color marking young at 9 weeks or older with a combination of green plastic leg bands and patagial markers, each bearing a unique white alpha-numeric code. Birds from the U.S. Virgin Islands were color-marked on the left wing and leg; birds from Puerto Rico were marked on the right wing and leg. Also, pelicans were banded with U.S. Fish and Wildlife Service, special aluminum, wide, size 9, butt-end bands, with prefix and consecutive numbers

stamped from top to bottom across the width of the bands. A total of 220 pelicans was banded of which 196 (89%) were banded as fledglings at Dutch Cap Cay, Montalva Bay, and Conejo Cay colonies. The remaining birds, including three adults, were captured and banded at San Juan Bay by luring them with bait fish.

During the course of field work conducted frequently throughout the study area, systematic searches were conducted for color-marked pelicans and individual codes were recorded. Rangers of the Department of Natural Resources and the general public were encouraged to report sightings and/or return bands of dead individuals. Cooperation was promoted by distributing posters throughout Puerto Rico, Culebra and Vieques Islands, and the U.S. Virgin Islands.

Habitat Use

Roosting and nesting habitats were described at San Juan Bay, Torrecillas Lagoon, Culebra and Vieques Islands, Ceiba, Jobos Bay, Parguera, Cabo Rojo, Anasco, Arecibo, Guanica and Guayanilla Bays, and Dorado lagoons. In the U.S. Virgin Islands, habitat analysis was conducted at nesting colonies on Dutch Cap and Congo Cays.

Used and non-used areas in mangrove systems in Puerto Rico and adjacent islands were compared using a variable plot cruising technique based on Bitterlich's (1947, 1948) method and adapted for mangroves by Cintron and Schaeffer-Novelli

(1983). Non-used areas were selected by superimposing a scaled grid system over fringe mangrove and mangrove islands shown on topographic maps. Sampling areas were selected by choosing grid coordinates from a random numbers table. Each coordinate was then located in the field and a starting point selected along the edge of the mangrove stand nearest the chosen coordinate. I then moved as many meters as indicated by a double digit figure obtained from a random numbers table. If the number was even, I moved eastward or northward along the edge of the mangrove stand; if the number was odd, I moved westward or southward. The sampling point was then placed at least 5 m, but not more than 10 m, along a line running perpendicular to the outer edge of the mangrove stand's root system. The actual distance between 5 and 10 m was obtained from a random numbers table.

At each of these sampling points, the following were measured: density of trees (DEN), tree diameter at breast height (DBH), maximum canopy height (HT), average distance of the trees to the ocean (DE), maximum canopy area (CA), slope of tree stems (SL), and the nearest distance (ND) to sources of human disturbance or pollution. Tree density was determined using a wedge prism with a calibrated basal area factor of 1 m^2/ha. Height, distance to edge, and maximum canopy area were determined using an optical range finder (Ranging, Inc., Model 120) calibrated for use between 2 and

30 m. Maximum canopy area was the product of the two longest perpendicular measurements of the canopy diameter made on each tree. These measurements were obtained by having 2 people with long poles stand under the opposite edges of the canopy while a third person measured distances with the optical range finder. Nearest distances to human disturbance and/or pollution sources were obtained from topographic maps. Slope of stems was classified subjectively as (1) vertical, (2) angled, or (3) horizontal. Height of nests, the diameter of the branches supporting nest structures and the distance those branches extended beyond the nests was also measured.

A total of 68 sampling sites was measured, of which 33 were non-used sites. Discriminant function analysis was used to construct a classification rule to identify potentially useful sites. Two discriminant functions were calculated. One function was built using all sites and included three species of mangrove. The second discriminant function was constructed using red mangrove (Rhizophora mangle) data only. A probability level of 0.01 was used to test for homogeneity of covariance matrices. Differences between structural parameters were examined using two-sample t-tests. Within each sampling site of the used areas, trees actually used for either roosting or nesting were identified. One-sample t-tests were used to identify differences of these particular trees relative to the overall means of used sites. An alpha

level of 0.05 was used to determine significant differences. Normal probability plots detected deviations from normality for DE in the non-used sites and for DEN of red mangroves in the used sites. However, t-tests using untransformed and log-transformed data, and assuming equal and unequal variances, yielded similar conclusions. Therefore, differences between individual structural parameters and the discriminant function presented in this work are based on untransformed data.

A chi-square contingency table was used to determine whether the frequency distribution of trees with vertical, angled, and horizontal slopes was independent of use classification. An alpha level of 0.05 was also used in this test.

Feeding Ecology

Feeding habitat was first identified by periodically surveying coastal areas from the ground or air and observing pelicans feeding. The general features of feeding sites at San Juan Bay, Torrecillas Lagoon, Culebra Island, Humacao lagoons, Jobos Bay, Parguera, Guanica and Arecibo Bays, and Dorado lagoons were described. Waters surrounding Dutch Cap, Congo, Lovango, Inner and Outer Brass cays, and Megan's Bay in the U.S. Virgin Islands also were described. For most of these sites, the mean depth, presence or absence of a protective barrier, distance to human disturbance or pollution sources were recorded. The relative importance of feeding

areas was determined by the frequency and numbers of pelicans observed. Areas were later classified as (1) important (50 or more pelicans nearly always present roosting, nesting or feeding), (2) moderately important (few to many pelicans often present but fluctuating seasonally or irregularly), (3) occasionally (few to many pelicans present depending on occurrence of large schools of fish).

Fish Sampling

Initially, the study objectives called for gill net sampling at as many feeding localities as possible. The sampling scheme was to set gill nets at "used" sites (i.e., where pelicans were seen feeding) and another set of nets at "non-used" sites. However, this scheme proved impractical because in most areas pelicans were widely dispersed and thus provided a poor indication of "good" sites. For this reason, fish sampling efforts were concentrated at three localities where pelicans were numerous and present year-round. These sites were San Juan Bay, and the lagoons at Dorado and Humacao. Incidental sampling was also done in the Parguera area, Culebra Island, Torrecillas Lagoon, and U.S. Virgin Islands.

At each of the three main localities, fish were sampled at intervals of 1 to 3 months. Six experimental gill nets (36.8 x 1.8 m) were used, each having three equal-sized panels with mesh sizes of 1.27, 2.54, 3.81 cm. Two sets of three

nets each were placed during mid-morning (0700-0900) and mid-afternoon (1500-1600) for two consecutive days. Later in the study, only one set was used to sample fish in small lagoons such as Dorado. The nets of each set were arranged in an H-shaped configuration with small-mesh panels of the parallel nets placed at opposite ends of the set. One set was placed as near the shoreline as water-depth (minimum of 1.8 m) would allow, with the parallel nets perpendicular to the shoreline. A second set was placed at least 75-100m farther from the shore. After one hour sampling periods, the nets were retrieved, placed in plastic drums, and taken to land to remove and process fish. Fish were identified and weighed. Species frequencies and the weight per species per panel were determined. Results are expressed as the mean number of fish of each species caught per panel and percent biomass of total catch per species.

The effect of time of sampling (TI), distance of nets from shoreline (SET), placement of the parallel nets (NET), season (MONTH), and mesh size (P) were examined using a nested-factorial analysis of variance. Time of day was assessed because pelicans could have been following a diel cycle associated with movement of prey species. Seasonal differences in food availability (catchability) within feeding areas were examined to determine if there was a relationship with seasonal fluctuations in pelican numbers. Mesh size was

expected to sort out prey species by size and weight. The effect of NET could not be measured at Dorado because Mata Redonda Lagoon and artificial ponds were relatively small and gill nets essentially extended from one shoreline to the other.

All data were log-transformed due to deviations from normality. Duncan multiple range tests were used to detect differences among means for those factors found significant in the analysis of variance. Type III sums of squares were used to construct the F-tests and Duncan multiple range tests.

While gill nets were in the water, the number of pelicans using the immediate areas was recorded and the number of successful versus unsuccessful dives tallied. Results are summarized as the percentage of successful dives for all pelicans according to age class. Data analysis was performed using G-tests (Sokal and Rohlf, 1969). In an effort to detect possible associations between catches of fish and 1) the total number of pelicans present at the entire locality (e.g., San Juan Bay), 2) the number of pelicans for which accurate observations of foraging success could be obtained at the fish sampling site, and 3) the percentage of successful dives of all pelicans, a Spearman rank correlation analysis was done between pairs of variables for the San Juan Bay data. The associative relationship between these variables for Dorado and Humacao lagoons are presented graphically because of

limited sample size for statistical analysis. In addition, an index of water turbidity between 1100 and 1200 was obtained by using a 0.3 m diameter Secchi disk.

Food Habits

Diet of pelicans was determined by collecting, identifying, weighing, and measuring prey items found in 44 regurgitations from nestlings, 10 from juveniles and adults captured at selected localities, and the upper digestive tract from 1 adult and 2 juveniles shot for toxicological evaluations (controls). Regurgitated food items were almost all intact. Nestlings regurgitated as nest contents were checked whereas handling juveniles and adults induced regurgitations. Efforts to increase the number of nestling regurgitations were not intensified because it would have meant shifting visitation hours to nesting colonies from early morning to late afternoons which might have caused undue stress to nestlings during the hottest part of the day.

Nesting Biology

Nesting colonies at Montalva Bay, Anasco Bay, Conejo Cay, Dutch Cap Cay and Congo Cay were monitored throughout the study. Data on nesting chronology, number of active nests, mortality of young, clutch size, brood size, and fledging were obtained. Nesting success is reported as the mean number of young fledged per nesting attempt and per successful nest.

Clutch and initial brood sizes at the Anasco colony were not obtained because nests were inaccessible.

After March 1981, colonies at Dutch Cap and Congo were visited at 6- to 8-week intervals and only the number of active nests and their contents were recorded. Incidental information on breeding efforts was also obtained at the Whistling Key and Mary Point colonies.

To minimize disturbance at nesting colonies, visits were spaced 2 or 3 weeks apart. Each visit lasted no more than two hours and was conducted between 0600-0900. Visits to Conejo Cay were conducted monthly.

Nests at Montalva Bay, Conejo Cay, and from September 1980 through March 1981 on Dutch Cap and Congo, were individually marked and their fates followed until young fledged or the nest failed. Nests at Anasco Bay were monitored from the ground. Human disturbance to nesting colonies was monitored during boat surveys and during my visits to the colonies. Human visitation rates to Conejo Cay were monitored by U.S. Navy personnel stationed at the nearby bombing range observation post on Cerro Matias, Vieques. The effect of ship-to-ground and air-to-ground bombardment on the pelican's breeding activities was monitored from the observation post on three occasions. The possibility that nesting activities were disrupted by the range activity was assessed by inspecting numbers of nest initiations for

comparable periods for Conejo Cay and Montalva Bay colonies. Range activity is defined as the percentage of days in which live ordnance was used in the target range.

Environmental Contaminants

A total of 30 eggs was collected and analyzed for two heavy metals and 13 chlorinated hydrocarbons pesticides and metabolites. Of these 30 eggs, 18 were collected at Dutch Cap Cay, 10 at Montalva Bay, and 2 at Conejo Cay. Analyses were performed by Hazleton Laboratories America, Inc. in Madison, Wisconsin. Residues are expressed on a wet weight basis. Fresh egg volume was estimated following procedures suggested by Tatum (1975). Eggshell thickness was measured with a micrometer caliper at three places around the equators of air-dried shells. A thickness index for these eggs was calculated according to Ratcliffe (1967).

Epizootics

Two pelican die-offs occurred in Puerto Rico in 1982, from February through August at Dorado, and from November through December at Humacao. A combined total of 152 pelicans died. Food samples from these birds were analyzed for contaminants at the laboratories of the Department of Agriculture in Puerto Rico. Water samples from Dorado were analyzed at the laboratories of the Department of Natural Resources for bacteria, pH, biological oxygen demand,

arsenate, lead, dissolved oxygen and phytoplankton composition. Pelicans in stress or dead were collected from both areas. These specimens were sent, in dry ice containers, to Patuxent Wildlife Research Laboratories in Laurel, Maryland, and to the National Wildlife Health Laboratories in Madison, Wisconsin for pathogenic and toxicological evaluation.

RESULTS

Population Size and Distribution

Aerial counts

Numbers of pelicans counted in 10 aerial surveys conducted quarterly between October 1980 and December 1982 remained generally stable (Table 1). Seasonal variation ranged from a low of 1,466 in fall 1980 to a high of 2,423 in winter 1980 (Appendix, Table 1). Highest counts were recorded in December in each of the three years. Seasonal fluctuations can be explained by the production of young following successful breeding seasons and emigration of adults from Puerto Rico to the U.S. Virgin Islands and perhaps elsewhere to breed.

The coastline of Puerto Rico was divided into two sections based on broad physiographic and physical characteristics as described in the Study Area section. The northern section (except for San Juan Bay) included the coastline from Rincon on the west side of Puerto Rico to Aguadilla, and east along the northern coast to Fajardo, on the northeastern side of the island (Figure 1). The southern section included the remaining portions of the island. Culebra and Vieques Islands were treated separately because they are located 27 and 9.6 km offshore, respectively. San Juan Bay is also treated separately because it supported the

Table 1. Average numbers ($\bar{X} \pm$ SE) of pelicans counted by air along the coastal zones of Puerto Rico and adjacent islands by quarter, 1980-82. March and June counts were done twice, in 1981 and 1982; October and December counts were done thrice, in 1980, 1981, and 1982

Location	March	June	October	December	Location Means
Puerto Rico, North	336 ± 55	217 ± 63	269 ± 57	357 ± 76	298 ± 33
San Juan Bay	270 ± 68	323 ± 14	225 ± 29	379 ± 85	293 ± 32
Puerto Rico, South	1183 ± 77	1164 ± 87	901 ± 67	1217 ± 27	1068 ± 53
Culebra Island	100 ± 66	68 ± 7	222 ± 123	245 ± 119	174 ± 52
Vieques Island	115 ± 51	151 ± 25	151 ± 20	81 ± 23	126 ± 14

highest concentration of pelicans anywhere in Puerto Rico and the U.S. Virgin Islands.

The southern coastline harbored about twice as many pelicans as its northern counter-part, including San Juan Bay, even though the length of each coastline is similar (Table 1). About half of all the pelicans counted on the northern coast each season were in San Juan Bay.

Average counts at Culebra Island were not significantly higher than those of Vieques Island ($t=0.84$, $P=0.41$)(Table 1). High counts at Culebra were observed during October and December whereas high counts occurred in June and October at Vieques. These differences are probably due to the geographic position of each of the islands. Culebra Island is closer to the Virgin Islands and in the path of pelicans flying to and from Puerto Rico. Vieques Island lies to the south of this flight path.

Geographic differences in pelican distribution are due, to a large extent, to the calm and protected waters of the southern coast of Puerto Rico and its associated mangrove and estuarine habitats.

In sum, counts remained generally stable throughout the study. Winter populations were 25% to 30% higher than summer populations. Post-fledging and post-breeding adult movements from the U.S. Virgin Islands to Puerto Rico were the major cause of seasonal population fluctuations.

Boat counts

Monthly surveys were conducted at seven localities to obtain information on numbers, age ratios, movement patterns, human disturbance, and behavioral patterns regarding feeding and roosting activities.

These counts showed seasonal fluctuations similar to the aerial counts. Locations along the northern coast followed a pattern similar to the aerial surveys with highest counts occurring during fall and winter. San Juan Bay had the highest mean count and numbers were the least variable (Table 2). Peak counts occurred between November and February. After 1981-82, counts tended to be sustained at higher levels (Figure 2).

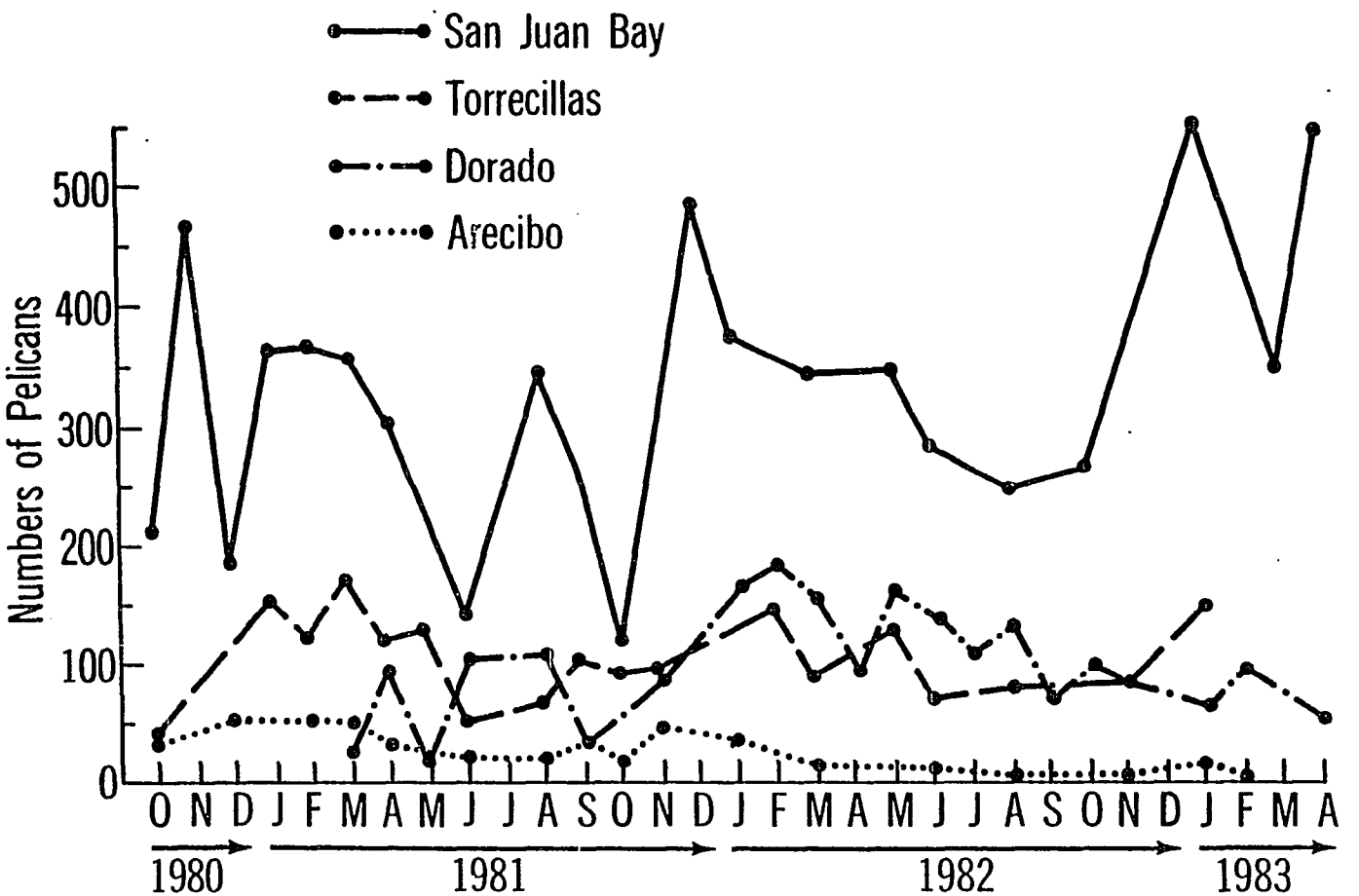
Torrecillas Lagoon and Arecibo Bay also followed a pattern of high fall-winter counts. However, numbers of pelicans using Arecibo Bay were highly variable (Table 2), but declined steadily during the study (Figure 2). Average counts at Torrecillas were greater that those at Arecibo Bay. An increase in numbers occurred at Dorado Lagoon during the first half of 1982, but pelican numbers dropped to 1981 levels by the end of 1982 and early 1983 (Figure 2). On the average, 89.7 $\pm$ 10.3 individuals were counted at Dorado during the study (Table 2).

On the southeastern coast, at Humacao (Santa Teresa Lagoon), increases in the number of pelicans occurred during

Table 2. Average numbers ($\bar{X} \pm SE$) of pelicans and juvenile-adult ratios observed during boat censuses at selected localities where pelicans tended to concentrate in Puerto Rico and adjacent islands (1980-1983)

	Number of Counts	Adults	Juveniles	Age Ratio	Unknown Age Class	Location Means	C.V.
San Juan Bay	21	129 ± 10.8	174 ± 16.9	1.4:1	20 ± 8.5	325 ± 25.4	35.9
Torrecillas Lagoon	18	44 ± 5.5	50 ± 6.8	1.1:1	7 ± 3.6	101 ± 8.6	35.9
Teresa Lagoon	15	37 ± 9.6	81 ± 12.8	2.2:1	51 ± 22.0	169 ± 20.5	47.0
Parguera Area	18	33 ± 6.3	27 ± 4.5		26 ± 13.3	85 ± 12.3	60.9
Arecibo Bay	18	2 ± 0.8	12 ± 4.2	6.8:1	9 ± 15.0	23 ± 4.1	74.5
Dorado Lagoon	22	17 ± 1.9	70 ± 8.8	4.1:1	2 ± 1.5	90 ± 10.3	53.8
Culebra Island	17	56 ± 10.5	56 ± 14.8	1.0:1	85 ± 32.2	197 ± 40.3	84.4

Fig. 2. Seasonal fluctuations in pelican numbers derived from boat counts along the northern coast of Puerto Rico at San Juan Bay, Torrecillas Lagoon, Dorado, and Arecibo Bay, 1980-1983.


San Juan Bay
Torrecillas
Dorado
Arecibo
Numbers of Pelicans
500
400
300
200
100
0
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
1980
1981
1982
1983

fall-winter with the highest increase in 1981-82 (Figure 3). A similar pattern occurred at Parguera but numbers were considerably lower than at Humacao (Table 2). Pelican numbers also varied seasonally at Culebra Island (Figure 3 and Table 2).

In sum, San Juan Bay and Humacao Lagoons had the highest mean counts among selected localities in Puerto Rico. Counts were highest during winter months following an influx of post-fledging and post-breeding individuals from the U.S. Virgin Islands.

Age ratios

On the northern coast, juveniles outnumbered adults in fall-winter months (Figure 4). In San Juan Bay, these differences were significant ($t=-2.59$, $P=0.02$). At Dorado Lagoons, juveniles also outnumbered adults significantly by a 4.1 to 1 ratio throughout the study ($t=-7.02$, $P<0.0001$).

Age ratios at various localities on the southern coast also reflected the increase of juveniles in the population during fall and winter (Figure 5). The number of juveniles per adult at Humacao (Santa Teresa Lagoon) exceeded 1. Although ratios became more equal towards 1983, juveniles outnumbered adults significantly ($t=-5.96$, $P<0.0001$).

Overall, ratios at Parguera favored adults but not significantly (Table 2). Juveniles increased in proportion after the breeding seasons and in the summer of 1981. Adults

Fig. 3. Seasonal fluctuations in pelican numbers derived from boat counts along the southern coast of Puerto Rico at Parquera, Humacao Lagoons, and at Culebra Island, 1980-1983.

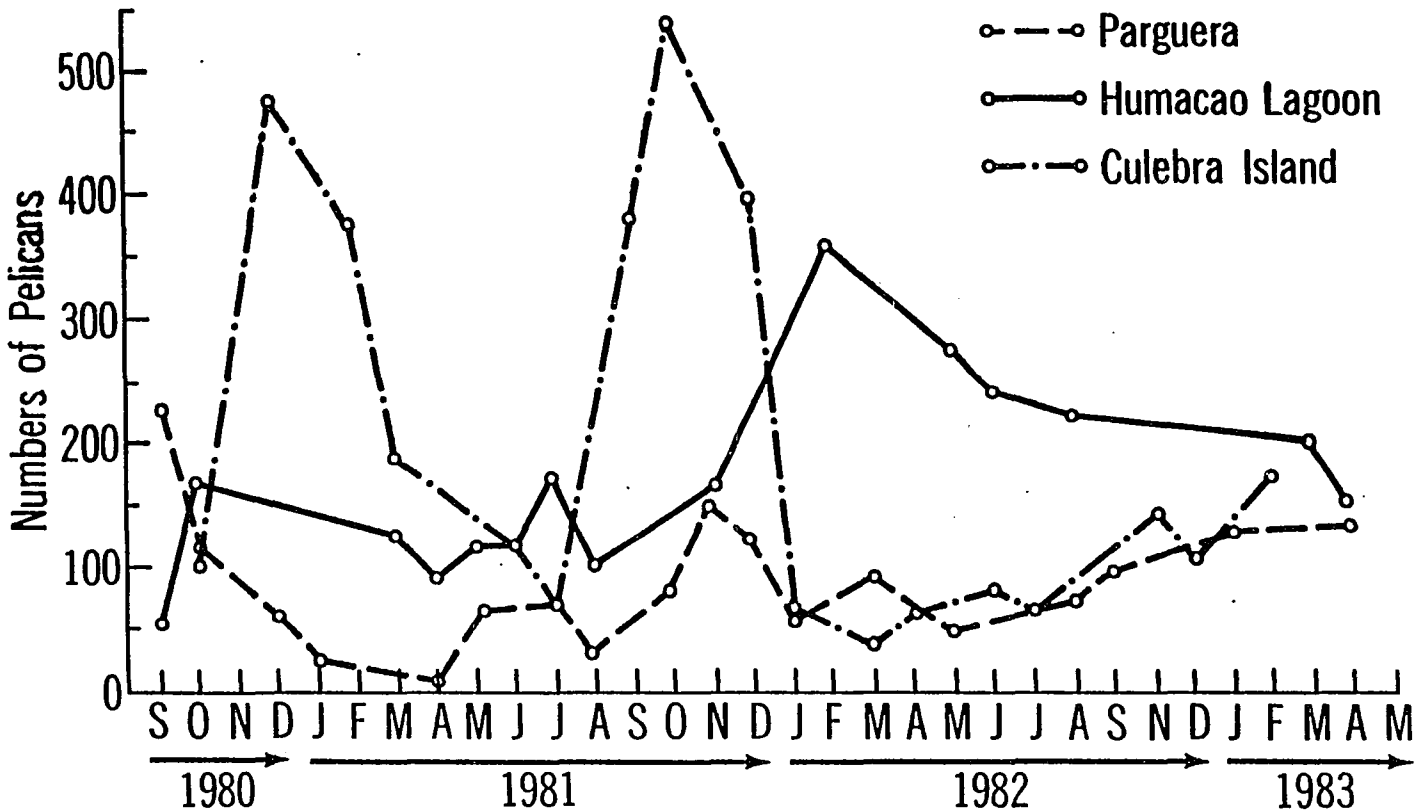

Parguera
Humacao Lagoon
Culebra Island
Numbers of Pelicans
0
100
200
300
400
500
S O N D J F M A M J J A S O N D J F M A M J J A S N D J F M A M
1980
1981
1982
1983

Fig. 4. Proportions of juveniles to adult pelicans derived from boat counts at San Juan Bay, Dorado Lagoons, and Torrecillas Lagoon, Puerto Rico, 1980-1983.

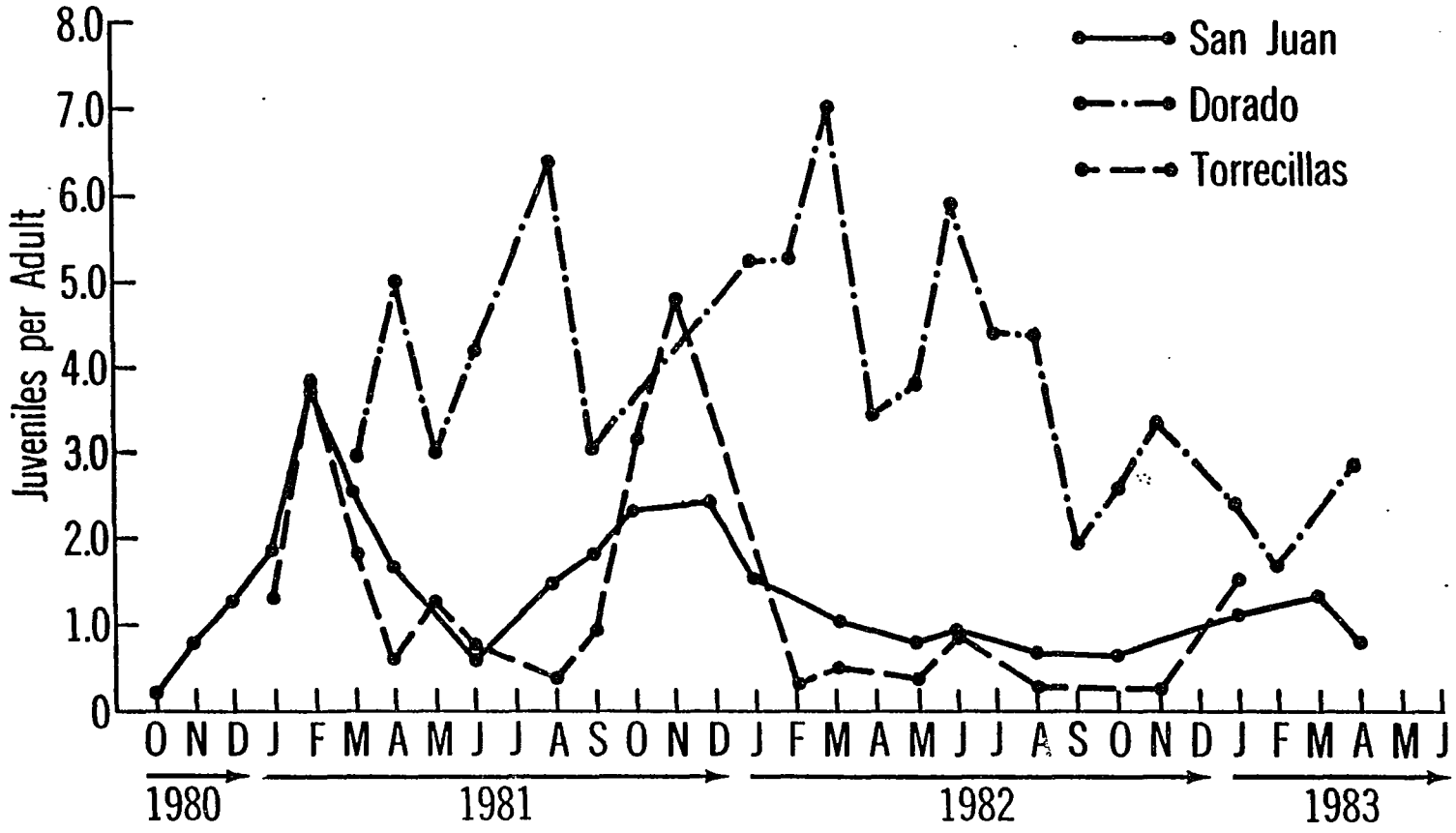
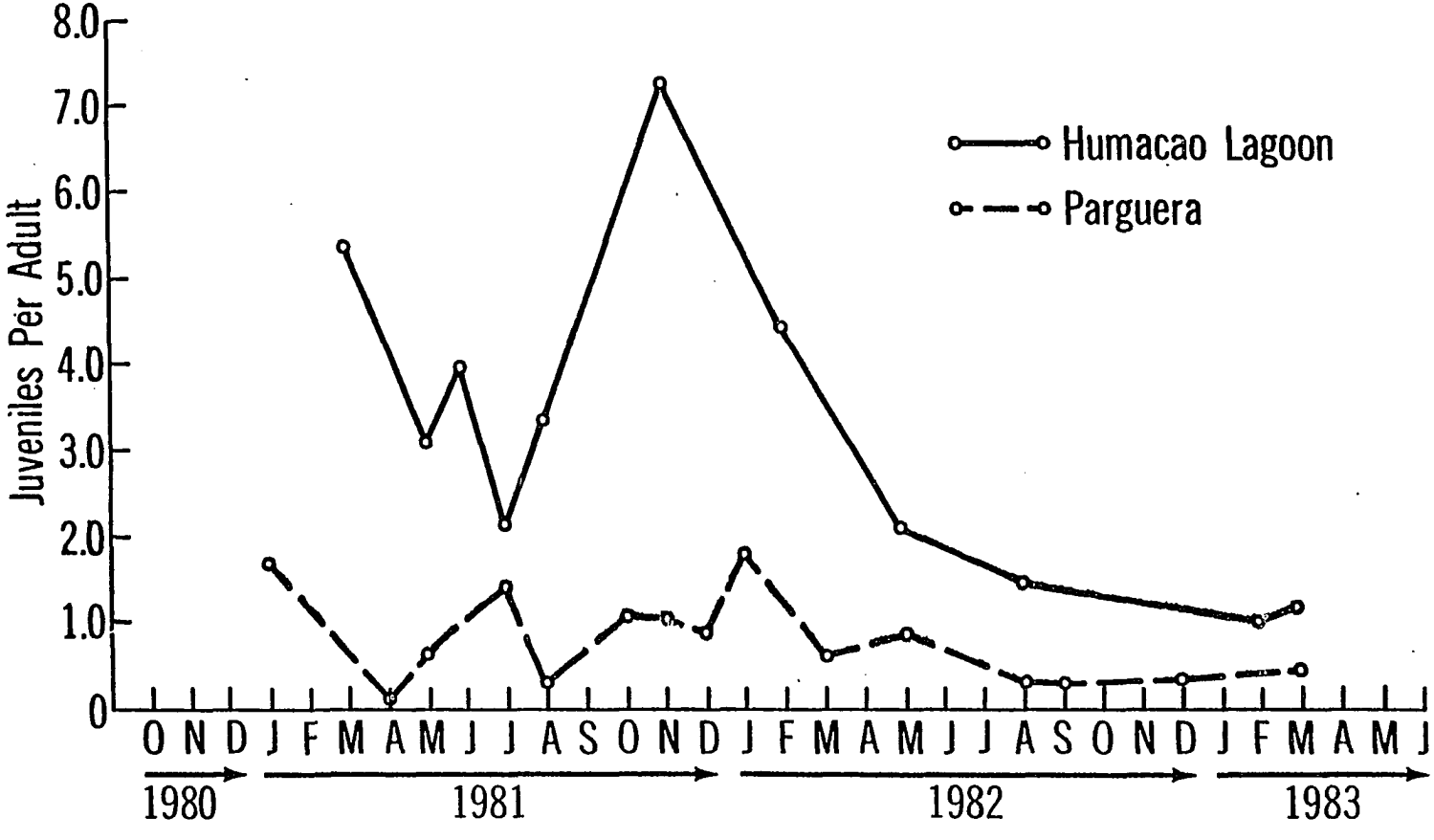

8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
Juveniles per Adult
San Juan
Dorado
Torrecillas
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
1980
1981
1982
1983

Fig. 5. Proportions of juveniles to adult pelicans derived from boat counts at Humacao Lagoons and Parquera, Puerto Rico, 1980-1983.


Juveniles Per Adult
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
Humacao Lagoon
Parguera
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
1980
1981
1982
1983

equaled or outnumbered juveniles near the onset of the breeding seasons (e.g., July, August, and early September) and during the first quarter of 1983.

In sum, age ratios favored juveniles during winter months following an influx of juveniles produced during the fall in the U.S. Virgin Islands. Ratios became more even as summer months approached.

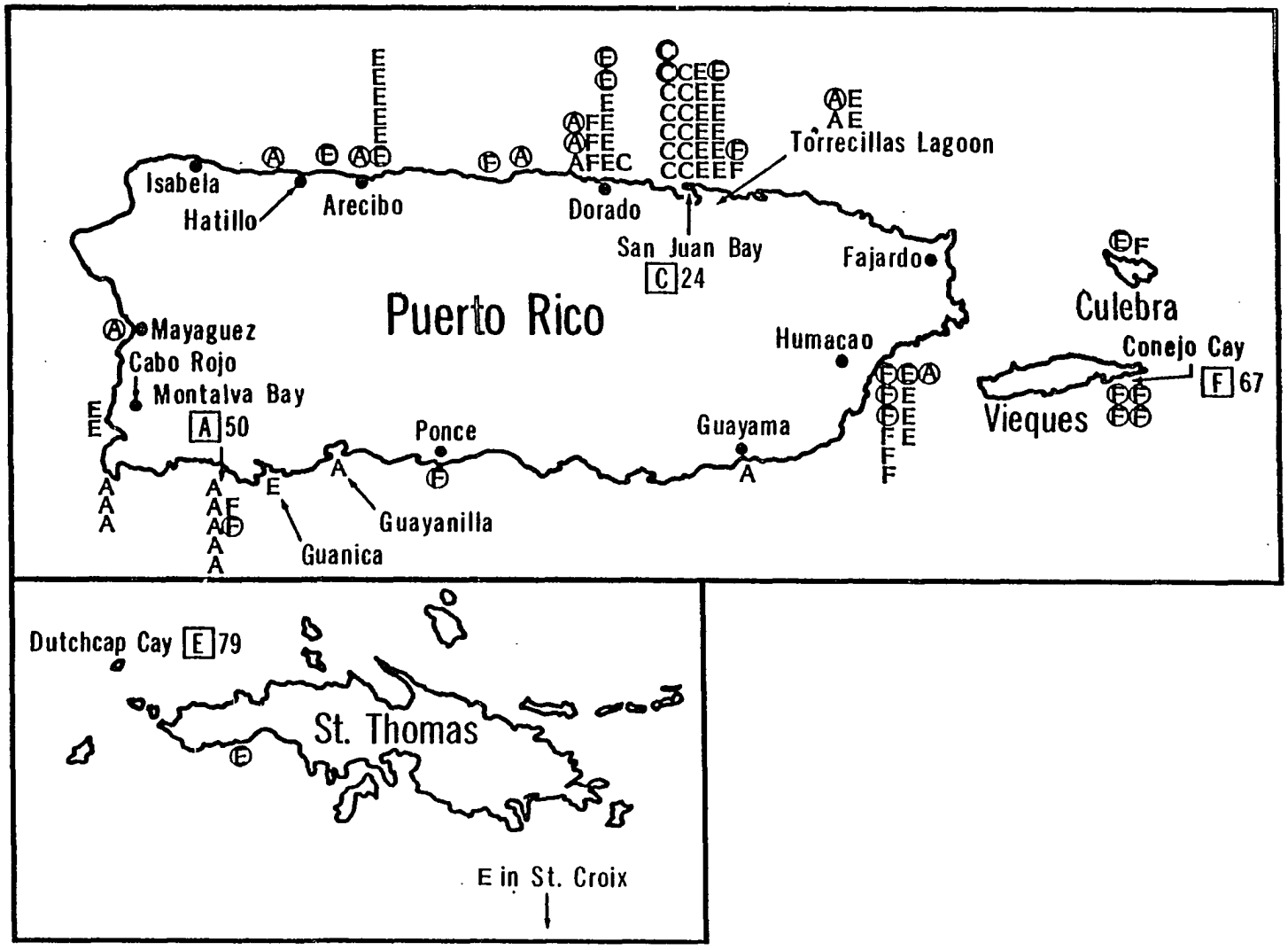
Movements

A total of 220 pelicans was banded and color-marked in Puerto Rico and the U.S. Virgin Islands; 79 nestlings at Dutch Cap Key, 50 nestlings at Montalva Bay, 67 nestlings at Conejo Key, and 24 juveniles and adults at San Juan Bay.

As of July 1984, 29 bands (13%) were recovered (Figure 6). All but two of these were recovered from juveniles which died less than six months after they were banded in the nest. The most bands recovered at a single locality was at the shallow lagoons of Humacao (Appendix, Table 2).

Seventy-three pelicans were identified at various localities by their alpha-numeric code (Figure 6). An additional 28 juveniles were identified as having been banded either in Puerto Rico (patagial tag on right wing) or the U.S. Virgin Islands (tag on left wing). Thus, 37 (47%) juveniles banded at Dutch Cap Key (U.S.V.I.) were later seen and identified in Puerto Rican territory. Only 15 (30%) and 16 (24%) individuals were positively identified as originating at

Fig. 6. Map of Puerto Rico and St. Thomas, U.S. Virgin Islands showing locations where pelicans were banded and color-marked (larger letters in squares) and where subsequently resighted (small letters) or recovered (small letters circled), 1980-1983. Numbers inside squares indicate numbers banded at each site. All pelicans were marked as nestlings except those at San Juan Bay (C) which consisted of 3 adults and 21 juveniles.


Isabela
Hatillo
Arecibo
Dorado
Torrecillas Lagoon
San Juan Bay
C 24
Fajardo
Puerto Rico
Culebra
Conejo Cay
F 67
Vieques
Humacao
Mayaguez
Cabo Rojo
Montalva Bay
A 50
Ponce
Guayama
Guayanilla
Guanica
Dutchcap Cay E 79
St. Thomas
E in St. Croix

Montalva Bay and Conejo Key, respectively.

Individuals E52 and E72 were sighted at 3 and 4 different localities during the study, respectively. These were Arecibo Bay, Dorado, Torrecillas Lagoon, and San Juan Bay; all sites are located along the northern coast. A fledgling (F11) banded on Conejo was seen on Culebra Island and then resighted at Humacao three days later. E52 was resighted 7 times within a period of 5 months. F09 and E06 were resighted five times each over a 3 and 4 months period, respectively. The former was resighted at Dorado and the latter at Humacao.

A large percentage of young banded in the Virgin Islands moved to Puerto Rico soon after fledging but none of those banded in Puerto Rico were seen in the Virgin Islands. Color-marked juveniles tended to concentrate at various feeding localities and generally moved only short distances or not at all. Color-marked individuals were not subsequently sighted at breeding colonies but tended to remain in the same general area for many months. Several color-marked individuals could still be seen at Dorado, Torrecillas, and Mandri Lagoons in December 1984.

Unidentified color-marked individuals were seen in most study areas and during aerial censuses. Except at areas where pelicans tended to concentrate, sightings were three times more frequent on the southern coast than elsewhere.

Only five recoveries or sightings were reported by the

public or non-DNR biologists during the study. Most of the sightings were recorded by me during regularly scheduled visits to study areas. Recoveries were mostly reported to me by DNR rangers.

In sum, post-fledging individuals move to Puerto Rico from the U. S. Virgin Islands. Once in Puerto Rico, individuals tended to stay in the same general locality. Highest mortality occurred within the first six months after banding.

Habitat Use

In the Virgin Islands, roosting and nesting occurred on six well-established offshore cays or remote locations within National Park Service jurisdiction. Because colonies are either inaccessible by sea or protected by the Park Service and the Division of Fish and Wildlife, these colony sites are not in any immediate danger of becoming altered or disturbed.

In Puerto Rico, 91% of all roosting and nesting sites identified during this study occurred on mangrove, particularly on red mangrove. Mangrove forests are subjected to continued pressure by human expansion. As of 1969, only about 25% of the original mangrove remained (Wadsworth, 1969). In view of the extensive use of mangrove by pelicans and the vulnerability of mangrove to human encroachment, a classification rule using discriminant function analysis (DFA) was developed in an attempt to provide a criterion to

prioritize potentially useful sites.

Roosting habitat

Roosting habitat was defined as those structures or vegetation which provided perches and which were consistently used by pelicans.

Mangrove Mangrove vegetation has been classified according to tidal flow and edaphic characteristics (Lugo and Snedaker, 1974). Brown pelicans in Puerto Rico used fringe mangrove bordering protected bays and coves along the coastline and overwash stands formed on small islets. Mangrove forests found within estuarine areas also were used.

Most sites were used opportunistically by feeding pelicans exploiting nearby food concentrations. However, several sites were used consistently and are considered traditional. A detailed analysis of these sites will follow in a subsequent section.

Casuarina Australian beef wood trees (Casuarina equisetifolia) are common along the coast of Puerto Rico where they serve principally as wind breaks (Little and Wadsworth, 1964). Casuarina trees were used as roosting sites by pelicans at Hotel Cofresi and Anasco Bay on the western coast, and Hatillo, Arecibo Bay, Dorado, and San Juan Bay on the northern coast. The structure of these sites is described in Table 3.

Rocky shore Rocky shores were used as roosting sites in the U.S. Virgin Islands. A rocky fringe surrounds most of the offshore keys in that area (U.S. Department Agriculture, 1970). Cays that were consistently used were Dutch Cap, Inner and Outer Brass, and Congo. In Puerto Rico, coral rubble was used in the Parguera area and Maunabo; both located along the southern coast.

Sandy beaches Roosting and loafing occurred on the western coast at the mouth of the Mayaguez River and on the banks of West Shore Cay located within San Juan Bay. In the Virgin Islands, pelicans consistently used the northern beach of Lovango Cay just south of Congo Cay.

Artificial structures These structures include small boat houses, piers, pilings, docks, and harbor markers. Most of them were associated with maritime traffic at Torrecillas Lagoon, San Juan, Jobos, Yabucoa, Guanica, Guayanilla, Arecibo, Parguera, Mayaguez (Marine Biology Field Station), and the beach area known as "Crash Boats" in Aguadilla.

Littoral and deciduous woodland These habitat types occurred on Dutch Cap and Congo and varied in size and species composition. On Dutch Cap remnants of deciduous woodland, 10-15 m tall, were found near the top of steep slopes in the central portion of the cay. Scattered woody vines were found in this woodland. Among the species used by pelicans were Ficus citrifolia, Bursera simaruba, Guapira fragans, Capparis

spp., Croton rigidus, and Pithecellobium unguis-cati. Evergreen littoral vegetation is associated in these cays with exposed rock (cliffs, rock boulders, and outcrops). Due to high winds, thin soil layer, and salt spray, scattered trees in this zone are no larger than bushes about 1 m tall. On Congo Cay, deciduous woodland constituted the most extensive vegetation, covering most of the top and southern slope of the cay. Woodland is better developed on the northern windward portion of the cay, which is dominated by a cliff running east and west. Species used by pelicans were Coccoloba uvifera, Ficus citrifolia, Guapira fragans and Capparis spp.

In sum, roosting habitat is varied in the Greater Puerto Rican Bank. In Puerto Rico, mangrove is the most important roosting habitat type, whereas offshore islands covered with littoral and deciduous woodland are most commonly used in the U.S. Virgin Islands.

Nesting habitat

Nesting occurred at eight different localities during this study. The following is a general description of the environment and habitat of all but the St. Croix colony. A detailed analysis and description of mangrove sites will be presented in a subsequent section.

Anasco Bay The nesting colony is located along the Tres Hermanos Beach in a small tract of Casuarina, Terminalia catappa, and Coccus nicifera, covering about 1,875 m^2. The

tract is bordered by coastal beach on the west and a small residential area about 0.5 km to the east. Fishermen have traditionally launched their boats and cleaned their nets within 125 m of the nesting colony. Interviews with local fishermen and residents suggested that this breeding colony has been active since at least 1954.

Pelicans nested in a row of eight large Casuarina trees (mean HT: 28.5 ± 2.4 m; mean DBH: 71.5 ± 1.8 cm) growing only a few meters from the beach. Nest structures were built at an average height of 20.6 ± 2.6 m. In September 1981, a nesting tree was uprooted by strong winds during a tropical storm. The diameter of nine branches supporting nests in the fallen tree averaged 5.1 ± 1.2 cm. Branches extended 2.9 ± 0.6 m beyond the nests which were constructed about 0.6 ± 0.2 m from the main trunk (Table 3).

Parguera The nesting colony was located on a mangrove islet in Montalva Bay referred to as Cayo Frios by Erdman (1967). Comprised of red mangrove, this islet covered an approximate area of 1,120 m^2. The nearest distance to human habitation was 1.7 km.

Other mangrove islets near Cayo Frios were used during this study at least once. During the 1981-82 season, the breeding colony was located about 0.8 km east of Cayo Frios. This islet is larger in area (2,490 m^2) and closer to human habitation (1.2 km). A chain of mangrove islets lies along

Table 3. Summary of structural variables of Casuarina equisetifolia trees used for roosting or nesting in Puerto Rico

Locality	Use[a]	No. Trees Used	Mean DBH (cm)	Mean Height (m)	Area
Añasco	R/N	8	71.5 ± 1.8	28.5 ± 2.6	1,845 m^2
Hotel Cofresi	R	4	49.6 ± 9.4		75 m^2
Hatillo I	R	16	56.3 ± 3.4	17.3 ± 0.6	275 m^2
Hatillo II	R	12	43.9 ± 4.2		
Dorado Beach I	R	3	56.0 ± 2.8	18.0 ± 1.0	500 m^2
Dorado Beach II	R	7	47.5 ± 5.5	15.3 ± 1.4	825 m^2
Arecibo Bay	R	3	46.8 ± 6.8	21.5 ± 2.5	450 m^2
San Juan Bay (Coast Guard Station)	R	8	93.7 ± 6.5	22.6 ± 0.9	3,046 m^2

[a] R=roosting; N=nesting.

the eastern outer limits of Montalva Bay growing on what is known as the Romero Reef Barrier. The tenth islet in this chain east of Cayo Frios was used during 1981-82, 1982-83, and 1984-85 seasons. In 1982 and 1984-85, the adjacent "ninth" islet was used.

Guanica Bay The nesting site was located on a small peninsula covered with fringe mangrove and adjacent to the sugar mill pier facilities located at the inner most part of the bay. The tract of mangrove vegetation used for nesting covered 150 m^2 and was located on the very tip of the peninsula. Only three trees were actually used in 1981. Nests (17) were built at an average height of 8.2 $\pm$ 0.2 m. These trees had a mean DBH of 35.6 $\pm$ 3.1 cm and were also used by nesting cattle egrets (Bubulcus ibis).

Conejo Cay Located on the southeastern tip of Vieques Island, this cay is about 1.2 km from a U.S. Navy bombing range and about 1.7 km from Cerro Matias. It covers approximately 3.8 ha with no easy access from the sea.

Vegetation on Conejo Cay was comprised of Coccoloba uvifera, Opuntia rubenscen, Capparis flexuosa, Pithecellobium ungis-cati, Sporobolus virginicus, and Ipomea tuba. The tallest vegetation used for nesting was Coccoloba uvifera. Average height of nests was 2.7 $\pm$ 0.4 m; mean diameter of branches supporting nests was 3.1 $\pm$ 0.7 cm. Nests built on a mix of Pithecellobium and Capparis, which grew in a dense mat

over the ground and over low bushes, were 1.0 ± 0.1 m above the ground. Nesting occurred on well-defined clumps of vegetation averaging 10.12 m^2.

Breeding activities on this cay were first noted in 1971 by Cameron Kepler who discovered the colony during a reconnaissance flight (Sorrie, 1975). Local people and fishermen were not sure how long pelicans have been using the cay. However, the cay was used as a target area by the Navy during the 1960s and bomb craters were still obvious. Thus, the colony site is probably not more than 20 years old.

Dutch Cap Cay Located 3.6 km northwest of Botany Bay, Saint Thomas, this roughly round-shaped cay is about 0.64 km^2 in area. The cay has no sandy beaches or coastal plains and is surrounded at water line by large volcanic boulders giving rise to steep slopes. The maximum elevation of the cay is 83 m above sea level. No stream or permanent body of fresh water is found on the cay. The vegetation is comprised of many native and pantropical weed species. Introduced domestic goats (Capra ircus) inhabit the cay and have affected the composition and distribution of the flora to a great extent. Rats (Rattus rattus) also occur on the cay.

Nesting was concentrated on guapiratum trees (Guapira fragans) which cover about 4.5 ha on the northeastern side of the cay. Density of stems in the stand was 297/ha. Mean DBH was 31.2 ± 1.5 cm, and mean height was 4.4 ± 0.1 m. Trees had

a canopy area of 41.9 m^2. Nesting trees supported an average of 2.4 nests. Branches supporting the nests had a mean diameter of 2.7 ± 0.1 cm and extended about 0.6 ± 0.02 m beyond the nest.

Clumps of Croton rigidus and Pithecellobium unguis-cati on the southeastern slopes of the cay were also used for nesting in 1980 and early 1981. Nests were built 0.5 ± 0.1 m above the ground on clumps averaging 2.2 m^2 in area.

Major types of vegetation on the cay were evergreen woodland, thorn scrub, cactus scrub, bushland, evergreen bushes, littoral vegetation associated with exposed rock, and deciduous woodland.

Congo Cay The cay is located 4.8 km west of Mary Point, St. John. It has a mean elevation of 49 m above sea level and is about 1.2 km long and 0.4 km wide. No permanent body of fresh water is found on the cay. The vegetation is natural and probably has not been disturbed in recent history. Steep cliffs about 58 m high dominate the northern edge of the cay. As on Dutch Cap, large boulders surround the cay and no sandy beaches or coastal plains are present.

Nesting occurred mostly along cliffs of the northern side (windward) of the cay. Tree species used for nesting were clumps of Capparis flexuosa, Guapira fragans, and Ficus citrifolia. Densities of these species outside the cliffs were 100/ha for Capparis, 260/ha for Guapira, and 80/ha for

Ficus. Of 102 nests for which tree species were identified, 34 (33%) were constructed on Guapira and 33 (32%) on Ficus. The other nests were built on mixed clumps of Guapira, Ficus, Capparis, Coccoloba uvifera, Croton rigidus, Bursera simaruba, and on various species of vines associated with the above trees. The average height of nests was 1.8 ± 0.1 m. Mean diameter of branches supporting the nests was 4.2 ± 0.4 cm, and the mean DBH of trees was 20.3 ± 4.9 cm.

Major vegetation types found on the cay were deciduous woodland, palm woodland, littoral vegetation associated with exposed rock and evergreen bushes.

Mary Point The nesting colony was on a mushroom shaped peninsula located on the northern section of St. John, in a 1100 m^2 stand of forest. Tree species used for nesting included Bursera simaruba, Guapira fragans, and Fiscus citrifolia. Boulders covered the shore from the sea to the forest's lower edge.

Whistling Key This small island is located about 400 m west of Mary Point. Rocky boulders surround the key, giving rise to steep slopes covered with lush vegetation. Nesting occurred on the northern face of the cay and on the same tree species on Mary Point.

In sum, mangrove and Casuarina trees comprised the nesting habitat in southwestern and western Puerto Rico. Littoral vegetation and scrubby deciduous woodland was the

most important nesting habitat type on Conejo Cay, Vieques, and in the U.S. Virgin Islands.

Comparison of mangrove vegetation used and non-used by pelicans

Used vs. non-used sites Structural variables were measured in 68 mangrove sites (Table 4). Of these, 72% were comprised of red mangrove, 19% of a mix of red and white mangrove (Laguncularia racemosa), 4% of black mangrove (Avicennia germinans), 3% of white mangrove, and the remainder of a mix of all three species. Used sites had significantly ($P<0.05$) larger DBH, HT, were closer to the edge (DE), and had a lower density of stems (DEN) than non-used sites. Canopy area (CA) was not significantly different among sites in any of the analyses.

Stem angle (SL) of mangrove trees did not differ significantly between used and non-used sites (chi-square=1.04; $P>0.05$). Trees actually used for nesting within used sites did not differ from non-used trees. However, sites used for roosting had significantly higher numbers of angled trees (chi-square=5.20; $P<0.05$). Angled trees were more common along fringes and overwash islets where mangrove trees could receive incident solar radiation from above and from the seaward side.

Nesting vs. roosting sites Nesting occurred entirely on red mangrove, and mangrove nesting sites had significantly

Table 4. Comparisons of five structural variables among mangrove sites used and not used by brown pelicans in Puerto Rico and adjacent islands

Variable	Use	Number of sites	Mean	S.E.	P [a]
Density (stems/site)	Non-used	33	5409.3	590.7	0.01
	Used	35	3557.8	503.1	
Diameter-breast-height (DBH) (cm)	Non-used	33	9.8	0.5	0.01
	Used	35	13.2	0.7	
Height (meters)	Non-used	33	4.9	0.2	0.01
	Used	35	6.5	0.2	
Canopy diameter (meters)	Non-used	10	9.6	1.7	0.23
	Used	10	14.5	2.9	
Distance to edge (meters)	Non-used	33	7.7	0.6	0.03
	Used	35	6.1	0.4	

[a] P=Probability of a larger t (two-tailed test).

lower density of stems (DEN) than unused mangrove (Table 5). All other variables did not differ significantly among usage categories.

Used trees vs used sites Structurally, trees actually used for roosting and nesting differed significantly from the overall means for used sites (Table 6). Trees used for nesting differed only in DE from trees used for roosting. Roosting trees were closer to the edge than nesting trees. As mentioned above, the stems of roosting trees were more often angled because their proximity to the edge of the stand results in an expanded crown extending toward the seaward side. This mixed branching pattern (i.e., vertical and lateral) seemed to provide more suitable perches for roosting pelicans than branches of trees toward the center of the stand.

Nest structure Nests in mangrove were constructed at an average height of 6.3 $\pm$ 0.2 m above the ground. Branches supporting nests averaged 2.7 $\pm$ 0.03 cm in diameter, extended 0.7 $\pm$ 0.04 m beyond the nest structure and served as perches for adults near the nest. Usually, nests were built on the very tops of trees causing apical damage. This mechanically induced damage was, to a large extent, the result of nest-building activities. In older colonies, it resulted in a flattened canopy that was probably more favorable for supporting nests. In newer colonies, canopy damage was not as

Table 5. Comparison of four structural variables among 11 nesting and 12 roosting sites of red mangrove in Puerto Rico and adjacent islands

Variables	Nesting	Roosting
	$\bar{X} \pm$ S.E.	$\bar{X} \pm$ S.E.
Density (stems/sites)	1760.1 ± 519.0	4439.4 ± 726.2[a]
Diameter-breast-height (cm)	15.2 ± 1.4	12.6 ± 1.2
Height (meters)	6.6 ± 0.4	6.8 ± 0.4
Distance to edge (meters)	5.4 ± 0.5	6.2 ± 0.8

[a] Significance at 0.01 level; t-test; d.f.=21.

Table 6. Comparisons of three structural variables among individual mangrove trees actually used for roosting and nesting with overall means for sites in Puerto Rico and adjacent islands

Variable	N	Used Trees	N	Used Sites	P [a]
		$\bar{X} \pm$ S.E.		$\bar{X} \pm$ S.E.	
Density-breast-height (cm)	191	16.9 $\pm$ 0.4	35	13.2	0.01
Height (meters)	182	6.8 $\pm$ 0.2	35	6.5	0.02
Distance to edge (meters)	139	4.2 $\pm$ 0.3	35	6.2	0.01

[a] P=Probability of a large t; one-sample t-test.

evident but twig removal was observed.

In sum, used sites had lower density of stems, higher diameter at breast height and height. Actually used trees, had higher diameter at breast height, height, and were closer to the edge of the mangrove's root system than the overall values for the used sites. Roosting sites had significantly higher angled trees than nesting sites.

Predicting potential use of mangroves

A discriminant function analysis, based on all mangrove sites, yielded a linear classification rule by which potentially useful sites of all mangrove species were evaluated (Table 7). The rule classified 74% of the used sites and 85% of the non-used sites correctly. However, since red mangrove was the most important tree species used by pelicans and is most threatened by human expansion, a second classification rule was constructed to assess red-mangrove stands only. This rule classified 87% of the used sites and 85% of the non-used sites correctly. The variance-covariance matrices and structural values of all sites are presented in Appendix, Tables 3 and 4.

One of the two types of misclassification error that is possible in the analysis deserves a closer examination, i.e., when a site was classified as non-used when in fact it was used. This kind of misclassification occurred in 13% of the cases using red mangrove data only and 26% of the cases using

Table 7. Discriminant functions and coefficients derived from discriminant function analysis used to classify used and non-used sites of mixed mangrove species and red mangrove in Puerto Rico and adjacent islands

All Mangrove Sites

$-4.34+0.0029(DEN)+0.0429(DBH)+0.9299(HT)+0.1939(DE) \geq 0$

Variable	Non-used	Used
constant	-32.37	-36.71
density (DEN)	0.0003	0.0032
diamter at breast height (DBH)	2.2470	2.2899
height (HT)	2.6872	3.6171
distance to edge (DE)	1.5075	1.3136

Red Mangrove Sites

$-3.83-0.0001(DEN)-0.0781(DBH)+1.2176(HT)-0.2944(DE) \geq 0$

Variable	Non-used	Used
constant	-32.71	-36.54
density (DEN)	0.0033	0.0032
diameter at breast height (DBH)	2.2168	2.1387
height (HT)	2.5839	3.8015
distance to edge (DE)	1.5668	1.2724

all mangrove data. Most of the misclassified sites were near traditional nesting sites (e.g., Parguera) or may have constituted essentially the only habitat available to pelicans at the locality (e.g., San Juan Bay).

At Parguera, mangrove habitat was readily available (i.e., there were over 50 mangrove islets in the area plus fringe mangrove along the coast line). Roosting or nesting sites averaged 3.5 km from each other and the total area extended only about 16 linear km along the coast. Food fishes were abundant in the root systems of fringe mangrove and overwash islets in this area and undoubtedly attracted any pelicans moving along the coast whether or not they nested in this area. Thus, the use of sites classified by Discriminant Function Analysis as "non-used" was probably the result of the extensive use of this entire area for foraging.

San Juan Bay also provided an abundant food supply for both maturing juveniles and adults in a well-protected harbor, but available overnight roosting sites in vegetation were limited to three areas. These were the Coast Guard facilities comprised of Casuarina, the Martin Pena canal comprised of mangrove forest, and the West Shore Cay in Bay View comprised of a mix of young Casuarina stands, mangrove, and littoral vegetation. These sites averaged 3.2 km but not more than 4.8 km apart.

The other kind of misclassification was a site classified

as "used" when in fact it was not. Apparently, factors other than vegetative structure also influence whether or not pelicans might use a site. These include distances from roosting and nesting sites to feeding areas, availability of food, human disturbance, and other unidentified factors (Briggs et al., 1981; Anderson and Gress, 1983). Given the vulnerability of mangrove forests to human disturbance, the predictive model presented here is conservative and errors slightly in favor of protecting mangroves.

In sum, the classification rule presented in this study is believed to be useful in assessing structural suitability of potentially useful sites. Compiling information on utilization patterns (e.g., frequency of use), historical use of the site or general area is also recommended to assist in reaching a decision.

Feeding Ecology

Feeding habitat

Any locality along the coastal waters of Puerto Rico, regardless of its calmness or depth, was used opportunistically when fish schools were detected by feeding pelicans. Most feeding areas, however, consisted of root systems of fringe and overwash mangrove, waters protected by coral reef barriers, and bays, estuaries, and lagoons.

Important feeding areas

San Juan Bay, Dorado lagoons, Humacao lagoons, and Parguera in Puerto Rico and all of the U.S. Virgin Islands are considered important feeding areas.

San Juan Bay This harbor includes about 739 ha of open water. The facilities within the harbor handle the great majority of the maritime traffic of Puerto Rico. For this reason, dredging has been extensive in maintaining wide channels averaging 22 m in depth; undredged areas averaged 2.4 m. Due to the harbor's shipping and manufacturing activities, the waters are turbid and polluted. The bay also receives considerable sewage effluent from San Juan, Catano, and other neighboring cities. The bottom of the bay is covered by a deep organic muck and is littered with waste materials.

Feeding pelicans concentrated in the Bay View area of San Juan Bay. This cove was bordered on the west by the Bacardi Rum Corporation, on the north by West Shore Key, and on the south by the township of Catano. It comprised 9% of the Bay's water surface area. The bottom was a soft organic muck covered with algae and seagrass. Water depth averaged 1.5 m. Fish were available year-round, with a corresponding concentration of pelicans in the area. Outside of Bay View, pelicans were seen feeding in low densities throughout the bay, particularly in the vicinity of roosting areas such as the Coast Guard Headquarters, and Martin Pena canal. Secchi

disk readings taken at various points throughout the bay averaged 0.62 ± 0.07 m.

Dorado Lagoons These were comprised of a series of artificial ponds and one natural lagoon called Mata Redonda. The primary purpose of the complex was aesthetic, but it also served as a water reservoir used to irrigate the golf course which surrounded the lagoon and ponds. Water levels were controlled by pumps. Occasionally, Mata Redonda lagoon received an influx of sea water when strong wave action occurred along the northern coast. These lagoons and ponds were stocked with Tilapia mossambica and Lepomis spp.

Feeding pelicans concentrated on Mata Redonda at Dorado Beach Hotel and on two artificial ponds on the Cerromar Hotel grounds. Mata Redonda had an area of about 6 ha. Its bottom was made up of soft mud primarily composed of clay (Negron et al., 1982). The Cerromar ponds averaged less than 1 ha in size and had hard clay bottoms. Secchi disk readings in the Cerromar ponds and Mata Redonda Lagoon averaged 0.37 ± 0.02 m.

Humacao Lagoons These lagoons are located on abandoned sugar cane plantations on an alluvial plain in southeastern Puerto Rico. The lagoons were once drained for agriculture but are now re-flooded due to elimination of water pumps. The lagoons are connected to the ocean by small creeks through which water may flow in either direction depending on tides or rainfall. The bottom of these lagoons is mostly

hardened silt. Presently, these lagoons are protected by the government of Puerto Rico as part of the Department of Natural Resources Refuge System.

Feeding pelicans concentrated on Santa Teresa Lagoon (76.6 ha open water) and on Mandri Lagoon (191.9 ha open water) where depths ranged from 0.5-1.5 m. These areas were open, and emergent vegetation was present only on the edges. Secchi disk readings in these lagoons averaged 0.38 $\pm$ 0.04 m.

Parguera This area contains the broadest shelf zone found in Puerto Rico. It extends seaward as far as 10 km in some sections (Morelock et al., 1977). Over 50 cays and islets were found within this area, most of which supported stands of mangrove (Martinez et al., 1979). Fringe and overwash mangrove were predominant with the largest tracts occurring in the Pitahaya area. Coral reefs and associated formations covered about 20% of the area and were largely responsible for dampening the energy of waves, a requirement for mangrove establishment. Seagrass (Thalassia spp.) beds were among the most extensive in Puerto Rico. Depths ranged from 15 to 18 m between the shore and the edge of the shelf (Martinez et al., 1979), and Secchi disc readings averaged 1.53 $\pm$ 0.41 m.

Pelicans are present year-round at Parguera but are most numerous during the extended nesting season which usually runs from June until February each year. Fish are potentially

available anywhere in these relatively protected waters, but pelicans were most frequently seen foraging near mangrove root systems.

U.S. Virgin Islands Collectively, the U.S. Virgin Islands support the largest breeding populations of pelicans in the region. Specific feeding areas were used opportunistically, although, I usually found fish schools near Congo, Inner Brass, and Outer Brass Cays.

Sites varied markedly with regard to bottom types and oceanic currents. Waters around Dutch Cap, Congo, and Inner and Outer Brass had bottoms typified by coral formations and sand. Commonly used areas around Dutch Cap and Inner and Outer Brass were deep and subjected to strong underwater currents. Hull and Megan's bays, located on the northcentral coast of St. Thomas and Lovango Cay, just south of Congo Cay, had a mix of sandy bottoms covered with seagrass and scattered coral formations and were protected from strong currents.

In spite of the relatively large numbers of breeding pelicans in the Virgin Islands, feeding aggregations around the islands were never as large as those seen in Puerto Rico. Danforth (1931) mentioned that groups he observed did not exceed 25 individuals. This was true in this study even when fish schools were present at localities such as Congo Cay and several species of seabirds were actively feeding. In most cases, I observed 5 to 10 pelicans exploiting these fish

schools. Perhaps, year-round food availability coupled with excellent water visibility (Secchi disc readings averaged 4.4 ± 0.82 m) allowed pelicans to forage more efficiently and thus spend less time feeding. Since feeding aggregations seldom exceeded 25 individuals, it is also possible that fish were more abundant and not as consistently concentrated at any one site as they apparently were in Puerto Rico.

Moderately important areas

Jobos Bay The bay and surrounding vegetation cover about 11,000 ha. It was the second largest estuarine area of Puerto Rico with as much as three times the amount of shoreline as any other estuary (Laboy, 1983). About 216 ha of Thalassia covered most of the muddy bottom; water depth averaged 3.8 m.

Guanica Bay The bay had about 12.5 ha of fringe mangrove along its northern and northwestern edge (Martinez et al., 1979). Feeding pelicans concentrated towards the inner sections of the bay where the bottom was a thick organic muck. Water depth averaged 4.5 m.

Torrecillas Lagoon Complex These brackish lagoons are part of the most extensive mangrove forest remaining in Puerto Rico. The complex is typical of the northern coastal wetland areas. The lagoon is connected to the Atlantic Ocean through a canal in the Cangrejos area. Fresh water flows in from creeks and canals along its eastern and southern border.

Currently, the lagoon receives an unusually high amount of sewage and waste materials from the neighboring Carolina area. As a result, these lagoons are among the most polluted in the island, and inner waters are highly turbid. Torrecillas Lagoon had an average water depth of 2.4 m and Secchi disk readings averaged 0.6 m. Pinones Lagoon, which is part of this complex, had an average depth of 0.8 m and mean Secchi disk readings were 0.6 m. Torrecillas and Pinones Lagoons cover an approximate area of 246 and 103 ha, respectively. Feeding pelicans concentrated mainly in the general area of Punta Larga and Punta Mosquito near the eastern end of Luis Munoz Marin International Airport.

Culebra Island Feeding occurred mostly in "Puerto Manglar" on the southeastern coast, and along the northwestern coastline of the island. These areas exhibited all or most of the physical characteristics outlined for areas such as Jobos Bay.

Seasonal use of Culebra's surrounding waters increased during late fall and winter when an influx of juveniles occurred, possibly moving from the U.S. Virgin Islands to Puerto Rico. Associated with this seasonal influx was the expressed belief among local fishermen that fish schools were more common during fall and winter than at any other time of the year; a contention that I could not document.

Vieques Island Vieques was not monitored as intensively as Culebra due to U.S. Navy restrictions. However, based on aerial censuses and visits by boat, it appeared that protected bays along the southern coast of the island provided habitat similar to Jobos, Guanica, and Guayanilla Bays. Some of these areas were Puerto Mosquito, Puerto Ferro, Bahia Tapon, and Ensenada Honda, all along the southern coast and close to the breeding colony on Conejo Cay. Large feeding aggregations were seldom seen and, when detected, were usually located towards the western and northwestern portions of the island. These areas were typified by sandy bottoms and extensive Thalassia beds. The northwestern coast also benefited from the protection afforded by the extensive pier facility built by the U.S. Navy a few km to the east. Shallow waters near the pier were consistently used by pelicans.

In Puerto Rico, feeding pelicans were consistently recorded in Guayanilla Bay, Puerto Real, Boqueron, and Salinas (Cabo Rojo). These areas shared similar physical characteristics such as the presence of reef barriers, overwash mangrove islets and fringe mangrove, protected coves, and shallow and heterogeneous bottoms consisting of a mix of sand, coral reefs, and Thalassia beds.

Occasionally important areas

The existence of these areas became obvious during aerial surveys conducted on consecutive days. A feeding concentration observed on one day of the aerial survey was often absent on the other day. A concentration of up to 75 pelicans and hundreds of other seabirds feeding on a large school of anchovies a short distance from shore occurred over a period of 3-4 days off Costa Azul (Luquillo) in October 1981. Despite repeated visits to this locality in subsequent years, no school of fish and only a few pelicans were seen. Similar observations were made at Arecibo Bay, Caja de Muertos Island, Berberia Cay, and in Aguadilla. Such feeding aggregations were common during winter. Thus, fish schools may potentially occur at any locality along the coastal zone of Puerto Rico, and pelicans can be expected to feed opportunistically on these passing schools.

In sum, feeding habitat in the Greater Puerto Rican Bank was typified by shallow waters interspersed with coraline communities. Sandy bottoms were mostly covered with seagrass beds (Thalassia), particularly in protected areas (e.g., bays). In closed impoundments, waters were shallow, turbid and bottoms were covered with soft mud.

Food habits

Food regurgitations from nestlings and a few juveniles and adults captured at selected localities provided

information on the species of fish that pelicans were catching. Stomach contents from 1 adult and 2 juveniles shot for toxicological evaluations (controls) are also included here.

Regurgitations at Parguera (Montalva Bay) consisted primarily of Jenkinsia lamprotaenia and Harengula spp. Other species found at this breeding colony were Mugil curema and Atherinomorus stipes. At Dutch Cap, regurgitations were dominated by Anchoa lyolepis, Jenkinsia lamprotaenia, and Harengula clupeola.

Overall, mixed regurgitations of Jenkinsia lamprotaenia or Anchoa lyolepis with Harengula spp comprised about 67% of the sampled biomass (Table 8). Five other species were identified in the analyses. Mean number of fish per regurgitation was 35.2, and averaged 5.9 $\pm$ 0.3 cm in length. Mugil curema, ranging in size from 10-15 cm, was the largest species found (Montalva Bay). Older nestlings and fledglings were being fed the same size fish as younger nestlings.

Prey species recovered at Conejo Cay were Harengula spp., Jenkinsia lamprotaenia, and Tilapia mossambica. Tilapia were found on two occasions beneath nesting bushes. Two of the three Tilapia found measured approximately 15-20 cm; a prey-size that is probably too large to be swallowed by nestlings less than 6 weeks old due to the fish's deep-bodied shape. This species occurs only in fresh or brackish waters and the

Table 8. Fish species occurrence in 57 stomach regurgitations from brown pelicans in Puerto Rico and the U.S. Virgin Islands

Species	Frequency of Occurrence	Percent	Total Wet Weight (grs)	Percent
Anchoa lyolepis	3	5.0	85	4.0
Jenkinsia lamprotaenia	5	9.0	262	11.0
Harengula sp.	10	17.0	109	5.0
Tilapia mossambica	8	14.0	198	8.0
Cetengraulis edentulus	2	3.5	24	1.0
Mugil curema	1	2.0	65	3.0
Opisthonema oglinum	1	2.0	---	---
A. lyolepis/Harengula sp.	7	12.0	945	40.0
J. lamprotaenia/Harengula sp.	14	24.0	651	27.0
C. edentulus/H. clupeola	2	3.5	25	1.0
T. mossambica/Harengula sp.	1	2.0	---	---
M. curema/J. lamprotaenia	1	2.0	---	---
J. lamprotaenia/Harengula sp./A. stipes	1	2.0	---	---
J. lamprotaenia/Harengula sp./C. edentulus	1	2.0	---	---

nearest known source was Humacao, 13 km northwest of Conejo Cay.

Food samples were not collected at Anasco Bay colony because nests were inaccessible. However, several dried Harengula and one Opisthonema were found on the ground beneath nesting trees. A regurgitation collected at a roosting site near Hatillo consisted of 15 Harengula.

Pelicans captured for banding or collected with toxicosis or disease were feeding on what was being caught in gill nets. For instance, fish species caught in nets in San Juan Bay were Cetengraulis edentulus, Harengula clupeola, and Opisthonema oglinum. Regurgitations from four individuals within the sampling area, contained 26 Cetengraulis edentulus and 4 Haregula clupeola. Fish in food samples averaged 5.94 $\pm$ 0.43 cm in length. The lengths of fish caught in gill nets were not measured but were generally larger than fish in regurgitations.

Five regurgitations obtained at Humacao and Dorado consisted only of Tilapia with a mean length of 9.96 $\pm$ 0.86 cm. On several occasions, pelicans were observed trying to swallow large-size Tilapia for periods of up to six minutes. As suggested above, difficulties in handling and swallowing Tilapia might be due to their deep-bodied shape. Other prey species of similar length (i.e., clupeids, engraulids) have a more slender body shape and are more easily manipulated and

consumed by both adults and juveniles.

Stomach contents of three pelicans shot at Cabo Rojo (Salinas Bay) contained an average of 109 fish in their digestive tracts of which 62% were Jenkinsia lamprotaenia and 38% were Harengula jaguana. Jenkinsia averaged 1.8 g in weight and 6.0 cm in length; Harengula averaged 2.46 g and 6.84 cm. Most feeding observed in this area occurred in and around mangrove root systems and matched the prey species found in the regurgitations collected from nestlings at Montalva Bay. In general, the diet of pelicans is rather uniform throughout Puerto Rico and the U.S. Virgin Islands. With the possible exception of Tilapia, adult and juvenile pelicans appeared to feed on fish of similar size as those being fed to nestlings.

In sum, Jenkinsia lamprotaenia or Anchoa lyolepis with Harengula spp. dominated the diet of brown pelicans in the Greater Puerto Rican Bank. Tilapia mossambica was an important prey species in closed impoundments. Adults and nestlings feed on the same fish species and size classes.

Variation of food abundance at selected sites

Fish were sampled with gill nets 10-14 times between March 1982 and May 1983 at San Juan Bay, Dorado and Humacao (Mandri and Santa Teresa Lagoons) for the purpose of monitoring abundance, prey species, and species composition (See Appendix, Table 5 for anova tables). Culebra Island,

Parguera, Torrecillas Lagoon and the U.S. Virgin Islands were also sampled once or twice with limited success.

San Juan Bay The highest aggregation of pelicans was recorded at San Juan Bay where feeding was usually observed in the Bay View area. Of the fish species caught in nets, three occurred in high numbers in the catches and were also important in stomach contents (Table 8). These species were Cetengraulis edentulus, Harengula clupeola, and Opisthonema oglinum. Cetengraulis was the most abundant (or catchable) species (90% of the catch) in the bay followed by Harengula (5%) and Opisthonema (4%). Similarly, Cetengraulis represented 92% of the total biomass caught, followed by Harengula (5%) and Opisthonema (1%). Other species caught in low numbers were not found in stomach samples. Thus, analysis of species abundance concentrated on the three species mentioned above.

Season, location, and mesh size were found to significantly explain most of the variation in the catches (Anova, $P<0.05$) of all three species.

The highest mean catches of Cetengraulis occurred in February 1983 (Table 9), whereas the other two species were caught in highest numbers in April 1982 (Tables 10, 11). Location of the nets relative to distance from shore affected catch differently. Cetengraulis was caught, on the average, more often away from the shoreline. The converse was

Table 9. Mean numbers of Cetengraulis edentulus caught per month, set, and panel in gill nets at San Juan Bay

Mean	Month/Year	Duncan Group [a]	Mean	Set [b]	Duncan Group	Mean	Panel [c]	Duncan Group
3.65	2/83	A	2.66	2	A	2.56	1	A
2.51	8/82	B	1.44	1	B	2.50	2	A
2.47	12/82	B				1.10	3	B
2.07	4/83	B C						
1.98	4/82	B C						
1.89	7/82	B C						
1.77	6/82	B C						
1.07	5/83	D C						
0.61	3/82	D						

[a] Means with the same letter are not significantly different.

[b] Set=location of nets; 1=inshore, 2=offshore.

[c] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

Table 10. Mean numbers of Harengula clupeola caught per month, set, and panel in gill nets at San Juan Bay

Mean	Month/Year	Duncan Group [a]	Mean	Set[b]	Duncan Group	Mean	Panel[c]	Duncan Group
1.16	4/82	A	0.78	1	A	0.76	2	A
1.02	12/82	A B	0.40	2	B	0.65	1	A
0.82	2/83	A B C				0.35	3	B
0.59	7/82	D B C						
0.47	4/83	D B C						
0.43	5/83	D C						
0.18	6/82	D						
0.16	8/82	D						
0.12	3/82	D						

[a] Means with the same letter are not significantly different.

[b] Set=location of nets; 1=inshore, 2=offshore.

[c] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

Table 11. Mean numbers of Opisthonema oglinum caught per month, set, and panel in gill nets at San Juan Bay

Mean	Month/Year	Duncan Group [a]	Mean	Set [b]	Duncan Group	Mean	Panel [c]	Duncan Group
0.84	4/82	A	0.38	1	A	0.54	2	A
0.35	7/82	B	0.10	2	B	0.13	1	A
0.33	6/82	B				0.04	3	B
0.09	5/83	B						
0.02	2/83	B						
0.02	12/82	B						
0.00	4/83	B						
0.00	8/82	B						
0.00	3/82	B						

[a] Means with the same letter are not significantly different.

[b] Set=location of nets; 1=inshore, 2=offshore.

[c] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

true for Harengula and Opisthonema. Small to medium mesh-sized panels caught significantly more Cetengraulis and Harengula than the largest mesh-sized panel. Opisthonema were caught more often in the largest mesh-sized panel.

For both Harengula and Opisthonema, the interaction between time of sampling and location were significant. Although time treated as a main effect was not significant, the interaction of time and location may be interpreted to mean that fish move toward and away from shore without regard to time of day.

In general, catches of Cetengraulis and Harengula, the only two species found in regurgitations of four pelicans captured in the bay, were highest during winter. This pattern coincided with the observed winter movement of juvenile pelicans from breeding colonies in Puerto Rico and the U.S. Virgin Islands to San Juan Bay. However, fish schools were seen in the Bay View area of San Juan Bay during most of the year, and Cetengraulis was caught in gill nets year-round.

According to the stomach contents recovered, pelicans were feeding on small-sized fish. It is assumed that catches by the smallest mesh panel are the best indicators of food availability, and Cetengraulis is evidently the most important prey species for pelicans in San Juan Bay. Moreover, pelicans were more numerous in the Bay during the period of the highest catches of this species (fall and winter).

Sampling efforts at other localities in San Juan Bay (i.e., Martin Pena canal) yielded very low catches (Table 12). Catches averaged 2.8 per panel for all species combined. Opisthonema was the most frequently caught species (97%) in this area, and 93% of the fish caught occurred in December 1982. Subsequently, the area was visited twice and catches averaged 0.2 fish per panel. Thus, on the basis of gill-net sampling and pelican feeding behavior, Bay View was the most important feeding area in San Juan Bay year-round. Other areas were also important intermittently during the year depending on the occurrence of fish.

In sum, catches of Cetengraulis, Harengula, and Opisthonema were higher during winter months at San Juan Bay. Cetengraulis edentulus is believed to be the most important prey species in the bay. Catches with small panels are probably the best indicator of Cetengraulis availability.

Humacao (Mandri Lagoons) These lagoons had the most diverse fish fauna of any of the areas sampled. However, catches were dominated by Anchovia clupeoides (70% of frequency and 47% of biomass) and Tilapia mossambica (11% and 27%). Thus, only Tilapia and Anchovia will be treated in this analysis. Of these species, only Tilapia was recovered from regurgitations from several sick pelicans captured in the lagoons in November 1982 and April 1983.

Season and mesh size affected catches of both species

Table 12. Mean numbers of fish (all species) caught in nets at various localities in Puerto Rico and the U.S. Virgin Islands. Panel I had the smallest sized mesh; panel III had the largest mesh

Site	Panel I[b]	Panel II	Panel III	Per gill net	N[a]
Parguera	0.32	0.16	0.65	1.15	34
Torrecillas Lagoon	6.83	20.16	12.50	39.50	6
Martin Peña (S.J. Bay)	1.78	4.36	2.14	14.67	24
St. Thomas (USVI)	0.64	0.78	0.07	1.61	28
Culebra Island	12.16	42.16	11.94	66.00	18

[a] No. of gill nets.

[b] Panel=mesh size; I=smallest (1.27cm), II=medium (2.54cm), III=largest (3.81cm).

significantly (ANOVA, $P<0.05$). Months with highest mean catches were April 1983 for Tilapia (Table 13) and September 1982 for Anchovia (Table 14).

The effect of location of nets on catch relative to distance from shore was nearly significant statistically ($P=0.06$). An inspection of the data revealed that Tilapia was caught, on the average, in higher numbers away from the shore whereas Anchovia was caught nearer the shore. It is reasonable to suspect these species to be physically separated in this habitat.

Catches of both Tilapia and Anchovia varied according to mesh-size of the net panels. Tilapia was caught in high numbers in the smallest and largest mesh-sized panels (Table 13) whereas Anchovia was caught most frequently in the largest mesh-size panel (Table 14). Anchovia individuals caught in these lagoons were large (over 15 cm).

Time of day affected catches of Tilapia (Table 13). Significantly higher catches were recorded during afternoons. However, pelican numbers and feeding success did not appear to be related to these differences in catchability.

Humacao (Santa Teresa Lagoon) Tilapia mossambica was the most numerous species caught (95% of all individuals) at Santa Teresa Lagoon and season and mesh size significantly affected catches (ANOVA, $P<0.05$) (Table 15). Highest mean catches of Tilapia were recorded in April 1983, but

Table 13. Mean numbers of Tilapia mossambica caught per month, time of sampling, and panel at Mandri Lagoons, Humacao

Mean	Month/Year	Duncan Group [a]	Mean	Time	Duncan Group	Mean	Panel [b]	Duncan Group
0.71	4/83	A	0.53	PM	A	0.44	3	A
0.58	6/83	A	0.09	AM	B	0.39	1	A
0.11	11/82	B				0.09	2	B
0.08	9/82	B						
0.06	2/83	B						

[a] Means with the same letter are not significantly different.

[b] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

Table 14. Mean number of Anchovia clupeoides caught per month and panel at Mandri Lagoons, Humacao

Mean	Month/year	Duncan Group [a]	Mean	Panel [b]	Duncan Group
1.41	9/82	A	1.43	3	A
1.28	4/83	A B	0.85	2	B
0.96	2/83	A B C	0.82	1	B
0.93	11/82	B C			
0.66	6/83	C			

[a] Means with the same letter are not significantly different.

[b] Panel-mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

substantial catches also occurred during fall and winter. Catches were most frequently taken with the smallest mesh size (Table 15).

Table 15. Mean numbers of Tilapia mossambica caught per month and panel in gill nets at Santa Teresa Lagoon, Humacao

Mean	Month/Year	Duncan Group [a]	Mean	Panel [b]	Duncan Group
3.74	4/83	A	3.08	1	A
3.45	2/83	A B	2.92	3	A
3.24	11/82	C	2.49	2	B
2.35	4/82	D			
1.71	9/82				

[a] Means with the same letter are not significantly different.

[b] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54), 3=largest (3.81cm).

Lepomis spp. were much more abundant at Santa Teresa (4% of the catch or 2.9 fish per panel) than at Mandri Lagoons (0.02 per panel). Thus, Lepomis should be considered a potential prey species for pelicans, particularly because their size ranged from 5-8 cm. However, stomach contents of captured pelicans in this lagoon in November and December 1982 consisted only of Tilapia (6.35 cm in length).

Dorado (Mata Redonda Lagoon) Catches in this lagoon consisted only of Tilapia mossambica. Season and mesh size significantly affected capture of fish (ANOVA, $P<0.05$). Highest catches occurred in February 1983 and the lowest in May 1983 (Table 16). The smallest and largest mesh-sizes caught the most individuals.

Pelicans captured from this lagoon in 1982 had only Tilapia (5-6 cm in length) in their stomachs. However, some pelicans were seen catching Tilapia estimated to be no less than 10 cm. A fish inadvertently dropped by a startled pelican measured 15 cm.

Dorado (Cerromar Ponds) Tilapia mossambica and Lepomis spp. were caught in these ponds. Mesh size for both species and time of sampling for Tilapia affected catches (ANOVA, $P<0.05$). Both Tilapia and Lepomis were more commonly caught in the smallest and largest mesh size panels (Tables 17, 18). Mean catches of Tilapia were highest during the afternoon. Seasonal effects were significant for Tilapia with

Table 16. Mean numbers of Tilapia mossambica caught per month and panel in gill nets at Mata Redonda Lagoon, Dorado, Puerto Rico

Mean	Month/Year	Duncan Group [a]	Mean	Panel [b]	Duncan Group
2.25	2/83	A	2.09	3	A
1.53	3/82	B	1.54	1	B
1.48	11/82	B	0.98	2	C
1.38	9/82	B			
0.90	5/83	C			

[a] Means with the same letter are not significantly different.

[b] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

Table 17. Mean numbers of Tilapia mossambica caught per time of sampling and panel in gill nets at Cerromar Pond, Dorado, Puerto Rico

Mean	Time	Duncan Group [a]	Mean	Panel [b]	Duncan Group
2.94	PM	A	2.84	3	A
1.95	AM	B	2.30	1	B
			2.02	2	B

[a] Means with the same letter are not significantly different.

[b] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

Table 18. Mean numbers of Lepomis spp. caught per panel in gill nets at Cerromar Pond, Dorado, Puerto Rico

Mean	Panel[b]	Duncan Group[a]
1.39	3	A
0.30	2	B
0.26	1	B

[a] Means with the same letter are not significantly different.

[b] Panel=mesh size; 1=smallest (1.27cm), 2=medium (2.54cm), 3=largest (3.81cm).

highest mean catches occurring in February 1983.

The dominant size class in this pond ranged from 6-8 cm and were suitably-sized prey for pelicans. Feeding activities were sporadic and evenly distributed between adjacent ponds.

Torrecillas Lagoon The most common species in catches (10.3 per panel) at Torrecillas Lagoon was Cetengraulis (Table 12). Panels with medium and large sized mesh caught the most fish. Harengula (1.27 per panel) and Opisthonema (1.2 per panel) followed Cetengraulis in catchability. Total catches per panel averaged 13.2.

Parguera In Parguera, catches averaged only 0.38 per panel. Of these, only Mugil and Opisthonema, which made up only 10% (7/68) of the gill net catches, were found in pelican stomach contents from this area.

Seining along the root systems of mangrove proved to be a more successful sampling method than gill netting. Three sweeps with a hand-carried seine (15 x 1.2 m) caught more fish (89 per sweep) than 30 hours of gill netting. Seining caught essentially all species identified in stomach samples collected at the Parguera nesting colony. In monthly visits over a period of three years, only one large fish school was seen in the Parguera area.

U.S. Virgin Islands As in Parguera, catches were low in the Virgin Islands (Table 12) because gill nets had mesh sizes too large for most of the fishes present. Large numbers

of fish, including most species and size classes obtained in pelican stomach contents, were observed swimming freely through all net panels. Moreover, because the water was extremely clear in these areas, fish were also seen avoiding the nets.

Culebra Island Catches at Culebra Island were unpredictable (Table 12). In April 1982, catches of Harengula humeralis averaged 32.6 per panel. A flock of 62 pelicans were observed feeding on this large school of fish which was located on the northern end of Puerto Manglar. At the time, the water was turbid (Secchi=0.76 m). In June 1981, only 1.1 fish were caught per panel, and all were Mugil curema. This pattern of low catches continued during the remaining visits to Culebra, scheduled every six weeks. Pelican feeding activities also remained infrequent around the island and so fish sampling was discontinued after seven visits.

Pelican numbers and fish abundance

The aggregation of non-breeding pelicans at certain localities for extended periods of time (several months to year-round) was assumed to be largely related to a relatively constant supply of food. Thus, the presence of pelicans was indirect evidence for classifying these localities according to their relative importance as feeding areas. Fish sampling with gill nets at these localities provided direct evidence that pelicans were feeding on locally abundant species. Fish

species composition of gill net catches and regurgitated stomach contents of pelicans were nearly the same at all localities.

If seasonal variation in fish abundance and pelican numbers could be correlated, it would be additional evidence that pelicans were attracted to these areas because of the food supply.

The areas selected for this analysis were San Juan Bay, Mata Redonda Lagoon and Cerromar Pond at Dorado, and Santa Teresa and Mandri Lagoons at Humacao. Successful gill net catches were made at these localities on several dates in 1982 and 1983. Pelicans, relatively abundant at these localities year-round, were counted during the time gill netting was in progress. Morning and afternoon data for both pelican numbers and gill net catches were averaged for each date because no differences in pelican numbers were detected between morning and afternoon sampling periods.

The best data set was from San Juan Bay. Neither the numbers of pelicans present in all of San Juan Bay on the day of fish sampling, nor numbers feeding in the immediate vicinity of the nets, were significantly correlated with gill net catches (Table 19). Because catches in net panel I (the smallest mesh size) are probably the best indicators of food available to feeding pelicans, correlation analysis was also done on panel I catches. Although correlation values were

Table 19. Spearman rank correlations (r_s) between catch per unit effort and abundance of pelicans and feeding success for 9 occasions (d.f.=7) at San Juan Bay (1982-83)

Catch/Effort	Total Number of Pelicans	Number of Feeding Pelicans	Percent Feeding Success
All species caught/gill net	0.41 (P>.2)	0.25 (P>.5)	-0.18 (P>.5)
All species caught/panel I[a]	0.61 (P>.1)	0.42 (P>.2)	0.53 (P>.2)

[a] Panel I=smallest mesh (1.27cm).

higher, they were not statistically significant ($P>0.05$).

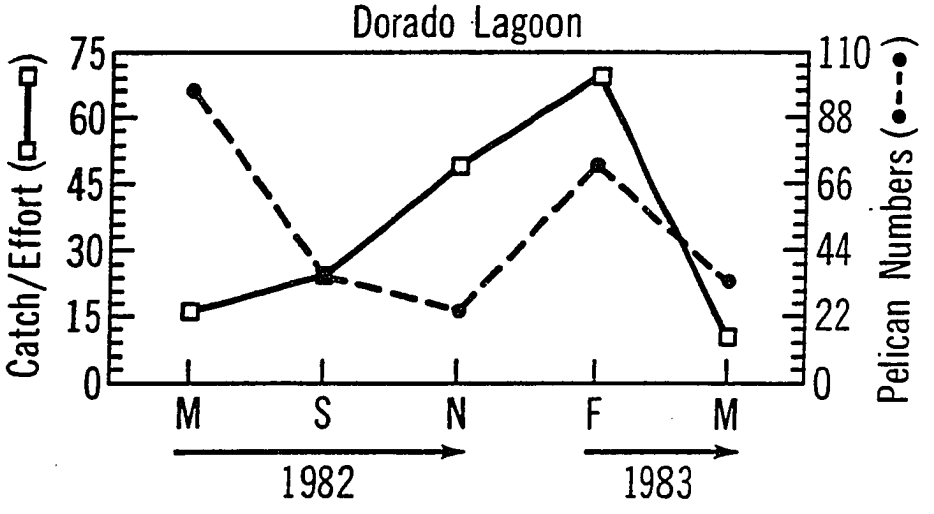
In general, highest gill net catches, especially in panel I, and pelican numbers in San Juan Bay occurred in late fall, winter and early spring. The number of sampling dates at the other four localities was insufficient for meaningful correlation analysis. However, graphic analysis (Figures 7 and 8) indicates some relationship between gill net catches and pelican numbers for Mata Redonda, Cerromar, and Mandri. Highest numbers of pelicans and fish caught were recorded in winter and early spring which coincides with the peak fledging of juveniles from breeding colonies.

Because of the large number of uncontrolled factors affecting sampling and variation in these two variables, the failure to obtain statistical significance with simple correlation analysis is not surprising. Much more extensive, and probably economically unfeasible, sampling efforts might establish an unequivocal relationship between these two variables.

Feeding success

Feeding success was monitored at five localities at the same time gill-netting was done (Table 20). Feeding success or failure was determined by observing the post-plunging behavior of pelicans as described by Orians (1969). A dive was considered successful if an individual, immediately after surfacing, held its bill partly under water and pressed the

Fig. 7. Relationship between food availability (catchability) and number of pelicans present at Dorado Lagoon and Cerromar ponds, Puerto Rico, 1982-1983.


Dorado Lagoon
Catch/Effort (□)
75
60
45
30
15
0
110
88
66
44
22
0
Pelican Numbers (●--●)
M
S
N
F
M
1982
1983

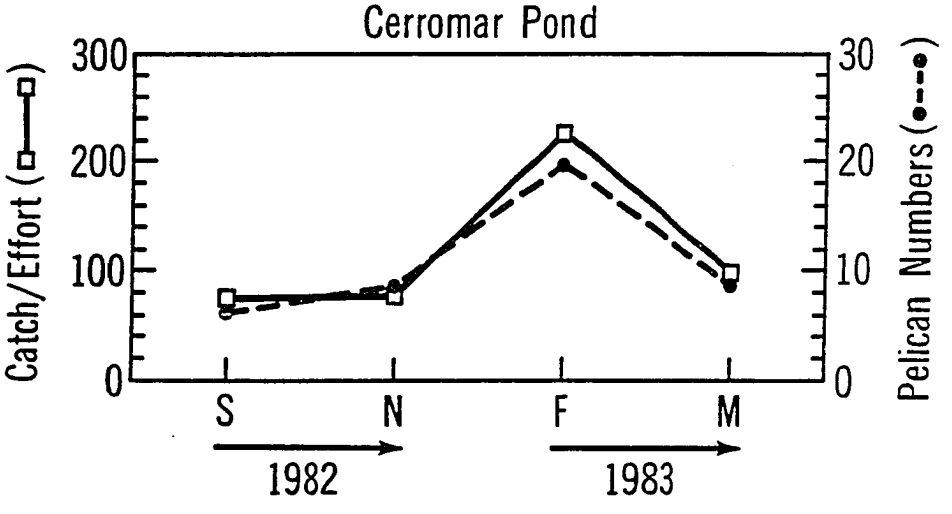
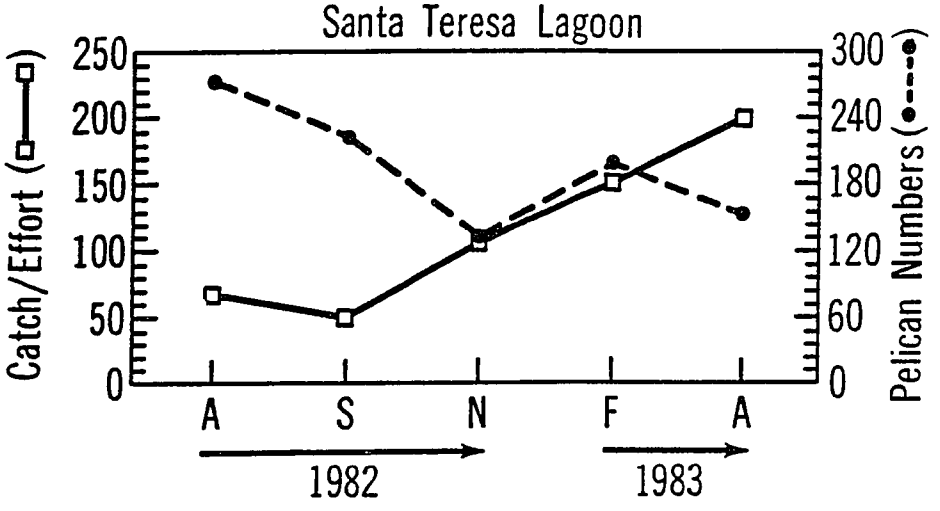

Cerromar Pond
Catch/Effort (□)
300
200
100
0
30
20
10
0
Pelican Numbers (●--●)
S
N
F
M
1982
1983

Fig. 8. Relationship between food availability (catchability) and number of pelicans present at Mandri and Santa Teresa Lagoons, Humacao, Puerto Rico, 1982-1983.


Santa Teresa Lagoon
Catch/Effort (□)
250
200
150
100
50
0
300
240
180
120
60
0
Pelican Numbers (●---●)
A
S
N
F
A
1982
1983

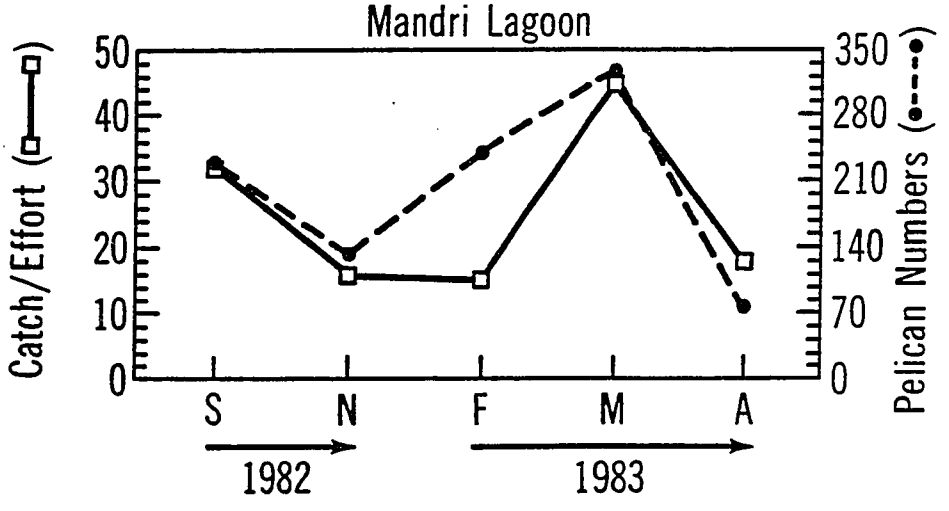

Mandri Lagoon
Catch/Effort (□)
50
40
30
20
10
0
350
280
210
140
70
0
Pelican Numbers (●---●)
S
N
F
M
A
1982
1983

Table 20. Comparison of feeding success of adult (A) and Juvenile (J) brown pelican at five localities of varying turbidities in Puerto Rico and the U.S. Virgin Islands (1980-83). Turbidity is expressed as the mean depth in meters of light penetrability as measured by a secchi disk.

	Turbidity(m) $\bar{X}$ (S.E.)	Age	Number of Feeding Dives		Percent	
			Successful	Unsuccessful	Successful	G (Age)
Dorado	0.37 (0.02)	A	18	79	18.56	4.324*
		J	46	389	10.57	
Humacao	0.38 (0.04)	A	50	373	11.82	0.134
		J	51	411	11.04	
San Juan Bay	0.62 (0.07)	A	308	1,307	19.07	2.024
		J	452	1,706	20.95	
Culebra Island	0.87 (0.06)	A	351	481	42.19	0.084
		J	168	222	43.08	
St. Thomas (USVI)	4.41 (0.82)	A	189	69	73.26	9.108**
		J	67	48	58.26	

Summary of G-tests for Independence

Hypothesis Tested	d.f.	
Locality x Age x Success	13	1,228.688***
Locality x Success	4	698.410***
Locality x Success (Adults only)	4	441.928***
Dorado x Humacao x San Juan Bay	2	54.608***
St. Thomas x All Others	1	334.590***
Humacao x Dorado	1	0.124
Age x Success	1	36.662***

Probability of a larger G-Value

* P - 0.05
** P - 0.01
*** P - 0.001

gullar pouch against its "chest". As a result, water was forced out of the pouch and the prey retained. Swallowing occurred soon after as the head was moved upward in a series of jerky motions. Unsuccessful individuals simply lifted their bills from the water almost immediately following a dive and did not swallow. The age (adult or juvenile) of each pelican was determined from plumage and noted after each observed dive.

Rates of success varied significantly between adults and juveniles and among localities (G-tests, Table 20). The age factor is highly significant ($P<0.001$) in favor of adults when all five localities are grouped, but was significant only at Dorado and St. Thomas when localities are tested separately. Adults had a 15 percent higher success rate than juveniles at St. Thomas and were 8 percent more efficient at Dorado. If the data for San Juan Bay, Humacao, and Culebra are grouped, the age effect is significant in favor of juveniles ($G=4.756$, $P<0.05$, $d.f.=1$). Age differences are apparently related to experience and learning (Orians, 1969; Schnell et al., 1983) but it is unclear why differences in adult-juvenile success rates varied so greatly between localities.

Feeding success rates were significantly different between all localities except Humacao and Dorado. Success rates increased linearly with increases in depth of $\log_{10}$ mean secchi disk measurements at the five localities (Table 21).

Table 21. Percent feeding success rates (FSR) regressed on turbidity (T Log_{10}) measured by secchi disks for adults, juveniles, and combined age classes for five sites in Puerto Rico and the U.S. Virgin Islands

Age class	Regression Equation	F^a	R^2
Adults	FSR = 38.9 + 55.2 (T Log_{10})	74.58	94.8
Juveniles	FSR = 33.1 + 45.0 (T Log_{10})	23.20	84.8
Adults & Juveniles	FSR = 36.1 + 54.0 (T Log_{10})	54.77	93.1

[a] Significant at 0.025 level of probability.

This is good evidence that pelicans feed more efficiently in clear than in turbid waters.

When setting gill nets, I often encountered dense fish schools that at the time were not being exploited by pelicans nor other marine birds. The startled fish would swim erratically, often near the surface, and cause pelicans and other birds to converge on the spot and begin diving. Thus, pelicans must rely, in large part, on their ability to see prey beneath the surface to successfully feed.

It is also possible that pelicans can detect fish movement near the surface enabling them to catch fish without direct visual contact. This would explain why pelicans concentrate in large numbers at localities where murky waters greatly reduce their ability to detect prey. Apparently, relatively greater density of fish at these localities also compensates for any reduction in feeding efficiency. The lack of adequate gill-net samples from clear water areas precluded statistical correlation of feeding success rates and fish abundance. Also, no correlation was found over time between feeding success and gill net catches in San Juan Bay.

The most turbid areas, Humacao and Dorado, are closed impoundments from which fish populations could not escape. San Juan Bay apparently supports an abundant fish population because of the high nutrient content in organic wastes that enter this estuary.

Productivity

Nesting seasons

The beginning and length of nesting seasons was highly variable depending on location of colonies. Colonies on the southwestern and western coast of Puerto Rico (Guanica, Montalva, and Anasco Bays) were usually active on a well-defined seasonal basis. Colonies at Congo, Conejo, Whistling Key, Dutch Cap, and Mary Point were active throughout most or all of the year.

At Montalva Bay, nesting occurred mostly on what is known as "Cayo Frios" (Erdman, 1967). This islet was used annually during 1977-1979 (Dr. James W. Wiley, U.S. Fish and Wildlife Service, Endangered Species Biologist, Palmer, Luquillo, P.R., personal communicator). During this study, the islet was used in 1980 and 1982. In 1981, pelicans nested on an islet 0.8 km to the east. Onset of breeding activities at these two sites was in May 1979, June 1978, July 1977, 1980, 1981, and August 1982. In 1983, reproductive activities had not yet commenced anywhere within the bay by 16 July.

In 1981 and 1982, small nesting colonies were also detected at Montalva Bay along the Romero Reef barrier. In October 1981, 24 nests were present, 6 of which had complete clutches on the "tenth islet" east of Cayo Frios (see nesting habitat section). Thus, colony initiation started sometime in mid-September. I believe that individuals in this colony

moved from the colony that had started in July just east of Cayo Frios. Renesting (or delayed nesting) was probably caused by the effects of a passing tropical storm south of Puerto Rico. On 4 November 1982, a second nesting colony was discovered in the bay on the adjacent "ninth islet". It was comprised of 6 nests which were abandoned by 3 December. The highest clutch size observed was 2 eggs in each of three nests.

A breeding colony with 18 nests and 29 eggs was discovered in Guanica Bay in October 1981. Only 7 eggs hatched. By February 1982, the colony had been abandoned and no young had fledged. As in the case of the second nesting colony found within Montalva Bay in 1981, these pelicans were possibly renesters from the main colony located east of Cayo Frios.

Pelicans at Anasco Bay started breeding in August 1981 and 1982. When first discovered in October 1980, this colony had young of 4-6 weeks of age. Therefore, nesting activities probably started sometime in July. In 1983, breeding activities commenced by 16 July.

At Conejo Cay, reproductive activities were recorded from October 1980 through May 1983. Only in July and August 1982 was there a complete absence of nesting activity. Breeding at Dutch Cap Cay occurred throughout the year. Continuous breeding was recorded on Congo Cay from September 1980 through

April 1982. Nesting activities started again in August and lasted until May 1983. Whistling Key and Mary Point colonies were active intermittently (Agardy, 1982).

Peak numbers of active nests were found at Dutch Cap Cay during September 1980 (195), and November 1982 (126). Peak numbers for Congo Cay were in September 1980 (86) and October 1982 (95). No data were collected during the same period of time in 1981. Highest number of nests at Whistling Key and Mary Point in 1980-81 occurred in September and October (13) and November (46), respectively.

In Puerto Rico, peak numbers of nests at Montalva Bay occurred in November and December 1977 (55) and 1978 (44), August 1980 (51) and 1981 (43), and September 1982 (51). At Anasco Bay, peak nest numbers were recorded in October 1981 (43) and September 1982 (42). On Conejo Cay, the highest number of active nests were recorded in August 1981 (43) and September 1982 (45).

In sum, onset of breeding activities in western and southwestern colonies in Puerto Rico may occur between May and August. In colonies located in the eastern part of the Puerto Rican Bank the breeding season is long with peak nesting activities occurring between September and November.

Nesting Success

Montalva Bay

About 43 nestlings of 6-8 weeks of age and younger were already present in the nesting colony when monitoring began in September 1980. Fledging rates of these individuals are believed to have been high because only 14 nestlings were found dead from September through February 1981. However, it is possible that some dead individuals were not detected due to the 2-week interval between visits. Nesting success for the 1980 season was calculated based on the number of new nests built or found with eggs in September. A total of 31 were found during that month and followed through fledging. The mean number of young produced per nesting attempt for these nests was 2.06 (Table 22).

Fledging rates for 1981 and 1982 were 0.71 and 0.68, respectively. The number of nests that never received eggs or were destroyed and abandoned was high (Table 22). In 1981, these nests were all deserted almost simultaneously. A tropical storm in September probably caused the desertion. In 1982, nest abandonment was distributed more or less evenly throughout the breeding season.

I believe that the second colony of 24 nests found within Montalva Bay in 1981 was comprised of pairs which originally belonged to the main colony located east of Cayo Frios. The mean number of young produced per nesting attempt was 0.42

Table 22. Nesting success of the brown pelican, Montalva Bay colony, southwestern Puerto Rico (1980-83)

	1980	1981[a]	1981[b]	1982
No. nests receiving at least one egg	31	39	20	54
No. nests not receiving eggs/destroyed	--	12	4	15
No. eggs laid	84	98	47	133
Clutch size	2.71	2.51	1.96	2.46
No. eggs hatched	79	74	31	69
No. eggs hatched per nest	2.55	1.90	1.55	1.27
Hatching Success	94%	75%	66%	52%
No. young that fledged	64	36	10	47
Percent eggs laid-fledged young	76	37	21	35
Percent eggs hatched-fledged young	81	49	32	68
No. successful nests	30	22	9	31
Percent successful nests	97	56	45	57
Young per successful nest	2.13	1.64	1.11	1.52
Young per nest receiving at least one egg	2.06	0.92	0.50	0.87
Young per total nesting attempts	2.06	0.71	0.42	0.68

[a] Colony east of Cayo Frios.

[b] Second colony on "tenth islet".

(Table 22). The islet east of Cayo Frios and those within the Romero Reef Barrier were previously unreported as nesting sites for pelicans in this area.

Anasco Bay

Monitoring of the breeding colony in this bay commenced in October 1981 when it was first discovered. A total of 18 nest structures were recorded. Mean young per nesting attempt in 1981 was 1.83 (Table 23). At the time of discovery, 7 young of different age classes were present; all fledged successfully. Production at this colony was lowest in 1981 with 0.51 young per nesting attempt. Seven nests and their contents were destroyed when a Casuarina tree was uprooted by wind in September. Production increased in 1982 to 0.86 young per nesting attempt.

Conejo Cay

Productivity at this cay followed a pattern observed at all colonies of high production in 1980 and lower in subsequent years (Table 24). Breeding activities were under way when the colony was first observed from a vantage point at Cerro Matias, about 1.2 km from the cay. Actual visits to the cay started in October 1981. A total of 9 nests, under construction or in egg-laying stage at the start of observations, produced an average of 1.77 young per nesting attempt. At this time, young of various age classes were

Table 23. Nesting success of the brown pelican, Añasco Bay colony, Puerto Rico (1980-82)

	1980[a]	1981	1982
Total number of nests	18	43	42
No. of nests destroyed/abandoned	2	19	7
No. of young fledged	33	22	36
No. successful nests	16	24	35
Percent successful nests			
Young per successful nest	2.06	0.92	1.03
Productivity (young/nesting attempts)	1.83	0.51	0.86

[a] October-January.

Table 24. Nesting success of the brown pelican. Conejo Cay colony, Vieques, Puerto Rico (1980-82)

	1980[a]	1981	1982
No. nests receiving at least one egg	9	92	41
No. nests not receiving eggs (unknown fate)	--	4(13)	8 (20)
No. eggs laid	26	224	98
Clutch size	2.88	2.43	2.39
No. eggs that hatched	23	159	57
No. eggs hatched per nest	2.55	1.73	1.39
Hatching Success	88%	71%	58%
No. young fledged	16	69	29
Percent eggs laid producing fledged young	61	31	29
Percent eggs hatched producing fledged young	69	43	51
No. successful nests	8	52	17
Percent successful nests	89	56	41
Young per successful nests	2.00	1.33	1.41
Young per nest receiving at least one egg	1.77	0.75	0.71
Young per total nesting attempts	1.77	0.72	0.59

[a] October-January.

numerous and 25, 6-9 weeks of age, were banded. Fledging rate of these individuals is also believed to have been high since the cay received little or no human disturbance and dead young were rare. Success rates in 1981 and 1982 were 0.72 and 0.59, respectively. In 1981, this breeding colony was the largest breeding colony in Puerto Rico with 92 nests initiated from July through December.

Congo Cay

From September 1980 to March 1981, 309 nests were recorded, of which 137 were usable for estimating a success rate of 1.16 young per nesting attempt (Table 25). The number of active nests seemed to follow a bimodal distribution with the first peak occurring in September, followed by a low of only 2 nest initiations in December 1980. Nesting activity again peaked during January 1981. Among 108 nests for which exact dates of initiation and fledging were known, the mean number of young per nesting attempt was higher for the period September-November (46 nests) than December-March (62 nests) (ANOVA, $P<0.001$). Early nesting pelicans had a higher mean clutch size (2.85) than those nesting later (2.65) (30 November). Similarly, those nesting early in the season fledged a higher mean number of young per nesting attempt (1.59) than those nesting later (0.95).

In August 1981, old nest structures were found throughout most of the island but were concentrated on the northern

Table 25. Nesting success of the brown pelican at Dutch Cap and Congo Cays, U.S. Virgin Islands (1980-81)

	Dutch Cap Cay [a]	Congo Cay [b]
No. of nests receiving at least one egg	53	137
No. eggs laid	141	348
Clutch size	2.66	2.54
No. eggs hatched	96	226
No. eggs hatched per nest	1.81	1.64
Hatching success	68%	65%
No. young fledged	86	159
Percent eggs laid producing fledged young	61	46
Percent eggs hatched producing fledged young	89	70
No. of successful nests	47	104
Percent successful nests	87	76
Young per successful nest	1.83	1.53
Productivity (young/nesting attempt)	1.62	1.16

[a] September-December, 1980.

[b] September, 1980-March, 1981.

slopes. Later in the season (January-March 1982), breeding pairs built nests over much of the southern slopes of the cay. This phenomenon was not observed again during the study because nesting was concentrated on the north-central slopes of the cay.

Dutch Cap Cay

In 1980, mean clutch size was 2.66 for 53 nests receiving at least one egg (Table 25). Mean number of young per nesting attempt was 1.62. This value is not significantly different from the 1.74 estimated for Congo Cay for the same period ($t=0.76$, $P>0.05$). On subsequent visits to the cay, fewer nesting attempts were observed (Appendix, Table 6). Nest structures in 1980-81 extended over the southern and southeastern slopes of the cay. Most of them were placed on low bushes almost at ground level. In subsequent years, this side of the cay was not used and nesting concentrated primarily in Guapira trees on the north side of the cay. A few nests were placed on small thorny shrubs of Pithecellobium.

Environmental Concerns

High human population densities and increasing industrialization of Puerto Rico and the U.S. Virgin Islands are reasons for taking a close look at the role of pollution, disease, and human disturbance in limiting the brown pelican

population in this region.

Contaminants

Metals Mercury (Hg) and lead (Pb) residues were measured in eggs collected in Puerto Rico and the U.S. Virgin Islands (see Appendix, Table 7 for individual sample values). Differences in residue levels of mercury between the two areas were not significant ($p>0.05$) and averaged about 0.21 ppm overall (Table 26). At Conejo Cay, mercury in the only egg collected was low (0.215 ppm). Traces of lead were detected in all egg samples.

The kidneys of three pelicans that died at Dorado Lagoons in April 1982 were analyzed for arsenic residues but none was detected.

Organochlorines DDE, DDD, and PCB (but not dieldrin) residues were significantly higher ($P<0.05$) in eggs from Montalva Bay than from Dutch Cap (Table 26). However, eggshell thickness and the thickness index did not differ among localities ($P>0.05$, Mann-Whitney test, Appendix, Table 8). Residue levels of organochlorines did not exceed the threshold level of 4 to 5 ppm believed to have caused eggshell thinning in mainland populations (Blus et al., 1974b). Eggshell thickness (0.496 mm) and thickness index (2.35) mean values were within the 95% confidence interval of mean values of pre-1947 eggs (0.510 mm and 2.42) (Anderson and Hickey, 1970).

Table 26. Geometric mean and 95% confidence intervals of mercury (Hg), DDE, DDD, dieldrin, and polychlorinated biphynel (PCB) residue levels in eggs collected at Dutch Cap Cay and Montalva Bay colonies

	Dutch Cap			Montalva		
Contaminant	95 C.I. -	G.M.	+ 95 C.I.	95 C.I. -	G.M.	+ 95 C.I.
Hg	0.1806	0.2347	0.3050	0.1477	0.1825	0.2255
DDE	0.0366	0.0660	0.1190	0.2230	0.6426	1.8509[a]
DDD	0.0069	0.0108	0.0169	0.0171	0.0261	0.0398[a]
PCBs	0.5385	1.0000	1.8568	2.0060	7.8450	30.6700[a]
Dieldrin	0.0080	0.0129	0.0208	0.0090	0.0281	0.0798

[a] Significant at 0.05 level; Mann-Whitney test.

Organochlorine residue levels in brains (ppm, wet weight) of three pelicans from Dorado Lagoons were low (Appendix, Table 12). DDE and PCB residues detected in only one individual were 0.99 ppm and 11.0 ppm, respectively. Dieldrin levels ranged from 0.28 to 2.0. None of these levels are believed to be hazardous to the health of brown pelicans (Dr. Richard M. Prouty, Chemist, U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Laurel, Maryland, personal communication).

Organophosphates A total of 127 pelicans died at Dorado between February and August 1982, and organophosphate pesticides were implicated. Peak mortalities (39) were recorded between 30 March and 9 April (Appendix, Table 9). No causative disease agents were detected among seven pelicans collected at Dorado in May 1982, and pesticide toxicosis was suspected.

A phytoplankton bloom at Mata Redonda was underway when the die-off was occurring but was not believed to be the causative mortality factor. Other water quality parameters measured did not suggest an unusual situation for this lagoon (Negron et al., 1982). Furthermore, fish and water samples were analyzed for diazinon, malathion, toxaphene, ethoprop (Mocap), and arsenic residues. With a low detection limit of 0.01 ppm (GC-ECD), none of these contaminants, known to be used on the golf course near the lagoon, were found

(Appendix, Tables 10 and 11).

Comparative activity of the neuroenzyme cholinesterase (Che) is a standard method for confirming organophosphate poisoning in organisms suspected of having organophosphate exposure. A threshold of 50% inhibition is indicative of organophosphate exposure (Hill and Fleming, 1982). Brain Che activity was determined in six pelicans that died at Dorado lagoons in 1982. Che activity was below the threshold in only one pelican, but activity was depressed 17-34 percent in four of the specimens compared to a mean based on brains from five unexposed pelicans collected from the southwestern coast of Puerto Rico. The activity in two of the six pelicans from Dorado was similar to the controls.

Although the Che determinations are equivocal, it is probable that organophosphates were responsible. Diazinon and ethoprop are highly toxic to birds (Hill et al., 1975). These pesticides were used on the golf course just before the die-off started, and the water in the lagoons is continually recycled through the irrigation system. Hence, any contaminants used on the course may eventually leach into the lagoons where pelicans fed. The adjacent Cerromar golf course, which contains numerous ponds used by pelicans, received the same pesticide treatment as Dorado, but not a single pelican was found dead or in stress. It was also interesting that at Dorado the only bird species affected by

the die-off were pelicans. It is possible, however, that the affected individuals of other species (e.g., herons) were dying at distant roosting sites.

Oil No evidence of oiled adults or eggs was detected at breeding colonies in Puerto Rico and the U.S. Virgin Islands. No major oil spills have occurred recently, although numerous minor spills have occurred at loading dock facilities. Unless a major spill occurs in this region, the localized nature of dock spills do not represent a major threat to pelicans.

Disease

An estimated 25 pelicans died during an epizootic die-off in November and December 1982 at Santa Teresa Lagoon, Humacao.

Three pelicans were sent to the U.S. Fish and Wildlife's Wildlife Health Laboratory, Madison, Wisconsin, for pathological evaluation. Two of these individuals died of botulism type C. The cause of death of the third individual could not be determined. No inhibition of brain Che was found in the three pelicans. It was not clear what caused the outbreak of botulism because water quality parameters were not assessed. It is possible that flash floods caused Frontera Creek to overflow into the lagoon resulting in a fish and macro-invertebrate die-off. This creek has been suspected of being contaminated with heavy metal and organic wastes from pharmaceutical and electronic industries located upstream.

Disturbance

Possible effects of human disturbance were assessed throughout this study during visits to roosting, nesting, and feeding areas. The nesting colony located at Anasco Bay seemed unaffected by the continued use of the beach by joggers, local fishermen, and a residential area about 0.5 km to the east. In fact, monitoring of the colony can be achieved without startling the pelicans by approaching on foot.

The breeding colony at Guanica Bay was 0.5 km from a residential area and the Montalva Bay colony was about 1.7 km from a fishing village. Colonies at Dutch Cap and Congo Cay are on relatively isolated and uninhabited cays with difficult access. Whistling Key and Mary Point, on the other hand, are located along a frequently used boat route between the United States and the British Virgin Islands. The high cliff on which they nested seemed to have provided the pelicans with enough isolation. Access by foot to these colonies is practically impossible.

Some traditional roosting sites also appeared unaffected by the proximity of human habitation and activities. Sites at Dorado and Cerromar hotels, Coast Guard facilities in San Juan Bay, and school grounds in Hatillo were all subjected to continued presence of humans and were used consistently by pelicans. Punta Larga and Punta Mosquito in Torrecillas

Lagoon, were located along the pathway of recreational and fishing boats.

I believe that human disturbance was not a major problem affecting the pelican populations in Puerto Rico and the U.S. Virgin Islands. In nesting colonies, where the impact of human disturbance would be highly detrimental (Schreiber, 1979), no evidence of persistent molestation was found. This was particularly true for colonies at Montalva Bay, where a common practice of local fishermen is to trawl along the perimeters of mangrove islets. During my three years of field visits to this area, not a single fisherman was seen in the immediate vicinity of the colonies. Conejo Cay is strictly off limits without permission from the U.S. Navy, and the cay is continually monitored from the Observation Post on Cerro Matias. At both of these nesting sites, signs of "no disturbance" were posted as a precautionary measure.

The U.S. Navy bombing range on Vieques, about 1.2 km from the nesting colony on Conejo Cay, presented the possibility of detrimental disturbance effects to nesting pelicans. The range could have adversely affected early-nesting activities such as nest site selection, pair formation, and nest construction. These activities can last up to a month (Schreiber, 1977). In spite of the intensity of range activity during the fall, nest initiation was not affected (Table 27). Pelicans seemed undisturbed by noise levels or

Table 27. Number of initiated nests at Conejo Cay and percent bombing range activity in Vieques, 1981-83

Month	Number Active Nests	Percent Range Activity
June (1981)	no visit	80
July	10	81
August	43	54
September	21	77
October	27	71
November	no visit	80
December	12	39
January (1982)	5	90
February	2	89
March	no visit	52
April	1	77
May	4	68
June	no visit	90
July	0	32
August	0	13
September	35	70
October	9	71
November	no visit	67
December	12	84
January (1983)	1	unknown

the passing of jetfighters during bombing exercises. Inspection of the total number of nests initiated during similar periods at Montalva Bay and Conejo Cay supports this view. Nest initiations followed the regional pattern of high nesting efforts during fall and lower afterwards; a trend observed in the U.S. Virgin Islands (Table 28). Furthermore, production rates during fall among all Puerto Rican nesting colonies did not differ significantly during the study (Kruskal-Wallis $H=0.09$, $P>0.10$).

Table 28. Number of nests initiated during similar periods at the Montalva Bay and Conejo Cay colonies in Puerto Rico

	1981		1982	
Month	Conejo	Montalva	Conejo	Montalva
July	10	24	0	0
August	43	15	0	29
September	21	2	35	9
October	27	10	9	14
November	no visit	0	no visit	16
December	12	0	12	1
TOTALS	113	51	56	69

DISCUSSION

Movements, Numbers, and Distribution

Short- and long-term fluctuations in population numbers and distribution of pelicans in the Greater Puerto Rican Bank Region cannot be assessed unless seasonal movements and their causes are better understood. Observations of color-marked nestlings and adults in this study provide insight into the patterns of movement and allow for reasonable speculation on their causes.

The U.S. Virgin Islands supported about 65 to 75 percent of the breeding population in the Bank region. Although some breeding continued throughout the year, breeding populations then were smaller than in the fall period. Most young fledged asynchronously during late fall and early winter with a detectable but ill-defined peak period of several weeks. As this peak period passed, juveniles, color-marked as nestlings in the Virgin Islands, began appearing in Puerto Rican waters where they remained for several months. A noticeable increase in non-breeding adults in Puerto Rico also occurred in winter and spring and it is believed that post-breeding adults were moving to Puerto Rico concurrently with recent fledglings. Conversely, many of the adults and nestlings banded in Puerto Rico were resighted later in Puerto Rican waters but not in the Virgin Islands.

The extent to which movement occurs outside the Greater

Puerto Rican Bank region is unknown. No reports of resightings or recoveries have been received, and no surveys were conducted. Such movement is believed to be minimal because of the relatively sedentary habits exhibited by marked birds once they reached Puerto Rico, and for various other reasons discussed below.

Factors responsible for the observed post-breeding movements from the U.S. Virgin Islands to Puerto Rico are difficult to identify given the tropical environment in which they occur. Briggs et al. (1981) found that among 7 environmental factors studied, surface water temperature best explained seasonal fluctuations and distribution patterns of California pelicans. Weather-related changes were suggested by Schreiber and Schreiber (1983) as an important factor influencing pelican movements south of Florida. Anderson and Anderson (1976) mentioned that pelicans from Mexico moved into California waters probably in response to a warming trend in water temperatures (Oceanic Period) which was correlated with high food abundance.

Warm water temperature in the Greater Puerto Rican Bank is probably not a determinant factor influencing observed movement and distributional patterns. Annual water temperatures vary only 2 to 4^{o} C (Frontenac et al., 1967). It is unlikely that such a subtle variation serves as a reliable cue for triggering dispersal or migration.

Water depth, another factor correlated with pelican distribution in California (Briggs et al., 1981), probably influences distribution in the Bank region because high productivity systems (e.g., corals and mangroves) are associated with shallow waters (Cintron et al., 1978; Velazco et al., 1985). Pelicans in the Greater Puerto Rican Bank region were never observed foraging in the open ocean; instead they concentrated along a narrow band of coastal waters and tended to be sedentary.

It is generally agreed that the distribution and abundance of food influences dispersal and distribution of seabirds. Schreiber and Schreiber (1983) hypothesized that food was the overriding factor influencing southern movements in Florida populations. Although distributional patterns of California pelicans were poorly correlated with regional indices of spawning northern anchovies (Briggs et al., 1981), Anderson and Anderson (1976) and Anderson et al.(1982) found a close relationship between pelican population fluctuations and different levels of food abundance. Anderson et al. (1980) also imply that pelican distributional patterns are closely tied with localized levels of food availability.

In my view, some of the factors explaining seasonal migration of pelicans between the Virgin Islands and Puerto Rico are: 1) the pelicans' tendency to wander away from the breeding grounds (perhaps related to food distribution), 2)

the tendency to fly west due to prevailing strong easterly and southeasterly winds during winter, 3) seasonal differences in food abundance, distribution or availability between Puerto Rico and the U.S. Virgin Islands, and 4) the tendency to return to traditional undisturbed breeding sites in the U.S. Virgin Islands.

Schreiber (1976) documented that young pelicans in Florida tend to wander during their first year of life. Juveniles and post-breeding adults in the Bank region also wander away from their breeding colonies but after reaching the coast of Puerto Rico appear to stay for extended periods. Adult-plumaged individuals banded as juveniles could still be seen in Puerto Rico 3 years after banding while none have been detected on breeding colonies in Puerto Rico and the U.S. Virgin Islands, or outside the Bank region. This suggests that juveniles stay in Puerto Rico until they reach breeding age (3 to 5 years).

Inter-island distances are probably not a constraint to pelicans in the Bank region considering that it is apparently energetically feasible for California pelicans to routinely fly 30 - 50 km to obtain food (Sunada et al., 1981). However, it is probably energetically less costly for pelicans "wandering" away from the U.S. Virgin Islands to follow the prevailing winds. Nelson (1983) hypothesized that it is advantageous for tropical seabirds, which have no need to

return to a fixed point (e.g., a nesting site), to wander unrestricted in search of more predictable food sources. Typically, food in tropical waters is patchy in distribution and less abundant than in temperate or polar waters.

Information on food abundance and distribution in the Greater Puerto Rican Bank region is unavailable except for that obtained in this study at selected localities in Puerto Rico. However, it is known that the species of fish eaten by pelicans usually spawn during winter and spring throughout the region (Erdman, 1976; Erdman et al., 1985), which coincides with observed peak fledging periods but not with initiation of nesting. Although I have no long-term data on fish populations in the U.S. Virgin Islands, it is improbable that food abundance drops dramatically during the period when the intensity of breeding lessens and the pelican population begins to shift toward Puerto Rico. Large schools of fish were occasionally observed near breeding colonies during slack breeding periods. When a school was present, food was abundant and available but the schools were distributed in widely-spaced patches both geographically and in time. Pelicans that were observed feeding in the clear waters of the Virgin Islands had a much higher success rate than pelicans in Puerto Rico's relatively turbid waters. Thus, it is probable that the patchy distribution of food in the Virgin Islands, perhaps coupled with a seasonal decline in overall food

abundance, is the reason for pelicans wandering from the area.

It is difficult for me to envision competition for food as a major causal factor behind migratory tendencies. This is because during and after peak breeding periods, feeding aggregations were small (not more than 10 individuals), and interference between individuals through agonistic behavior was never observed. The monopolization of a feeding area or its resources would have been unfeasible energetically for any individual. Competition for food in seabirds is difficult to establish when mostly density independent factors influence their food base regardless of whether they are in a temperate or tropical environment (Anderson et al., 1982; Nelson, 1983).

It is apparent that Puerto Rico's coastal waters act as an important food reservoir where young pelicans can grow and mature, and adults can meet minimal nutritional maintenance requirements. Food is concentrated in major estuaries and is available year-round. Thus, many individuals interrupt their wandering behavior and remain in Puerto Rican waters for extended periods.

Consistently high pelican aggregations were observed where food was constantly available year-round. These food resources were closely associated with extensive mangrove communities along Puerto Rico's coastal zone, particularly in the south, and, nutrient rich estuarine systems such as Humacao and Torrecillas lagoons and San Juan Bay. Even an

artificially stocked population of an exotic species (Tilapia) in a freshwater lagoon (Dorado) on a busy golf course was exploited annually by pelicans. Apparently, the predictability of the food source in these localities offsets the disadvantage of lower feeding success rates due to high turbidity.

It is likely that adults meet their pre-breeding nutritional requirements in Puerto Rico before returning to their respective colonies to breed. It would be interesting to investigate whether birds from the U.S. Virgin Islands acquire nutrient reserves in the way of increased body fat or protein before returning or whether food resources improve near their colonies. The return migration of pelicans to the U.S. Virgin Islands is probably also influenced strongly by tradition.

Census data indicate that summer age ratios were more even or favored adults, particularly near breeding colonies. Summer counts are difficult to interpret because they do not necessarily indicate the upcoming breeding population size (Anderson and Gress, 1983). Some adults may not join the fall breeding efforts because they have not met pre-breeding nutritional requirements (Schreiber, 1980b). Summer decreases in pelican numbers in Puerto Rico can be explained by 1) the movement of breeding adults to the U.S. Virgin Islands or elsewhere to breed as suggested above, 2) emigration and

continued wandering of juveniles, and 3) high juvenile mortality. Of these alternatives, juvenile mortality probably accounts for much of the decline in juveniles in the population.

Environmental Factors Affecting Food

Many physical factors affect significantly the intensity and breadth of the pelicans' food base. In California, factors such as surface water temperature, upwelling, and advective currents positively influence their food base (Anderson and Anderson, 1976; Briggs et al., 1981; Cheldon, 1981). In contrast, tropical waters are poor in terms of nutrients, and physical factors operating in the Bank region fluctuate in an unpredictable pattern. No consistent upwelling or advective current affects the Greater Puerto Rican Bank region (Dr. Juan G. Gonzalez, Marine Biologist, University of Puerto Rico, Mayaguez, P.R., personal communication). Upwellings may occur between Punta Tuna (southeastern Puerto Rico) and Vieques Island where a current deflection occurs (Heatwole et al., 1981) and possibly northwest of Puerto Rico. Additional nutrients might reach Bank region waters with the North Equatorial Currents transporting nutrient-rich waters from the Orinoco and Amazon basins.

Available information suggests that these currents affect productivity year-round. However, they exhibit poor constancy

in time and intensity, and thus a predictive model to encompass their full consequences has not yet been developed (Dr. Juan G. Gonzalez, Marine Biologist, University of Puerto Rico, Mayaguez, P.R., personal communication). Primary productivity indices can vary widely from one oceanographic region to another. Gonzalez (1967) found that there was significantly higher primary productivity in northwestern Puerto Rico as compared to the southwestern oceanic region adjacent to Parguera, site of a traditional nesting colony. Marine currents probably affect the food base of pelicans in the Bank region most significantly during late fall and winter.

It is likely that rain runoffs contribute to the enrichment of shallow coastal waters in the Bank region. This is particularly true around the large island of Puerto Rico which has several major estuaries and extensive mangrove systems. The impact of these runoffs is more noticeable closer to shore. This impact is usually short-lived (from a few days to several months) but can have significant consequences on the fish community. Glynn et al. (1964) documented a plankton bloom following heavy rains in 1963 and local fishermen believed that fish catches were higher that year. The passing of a tropical disturbance can also influence the marine community. Such weather disturbances break the thermocline and thereby let cooler and usually

richer waters reach the euphotic zone.

Foraging Behavior

Orians (1969) hypothesized that adult brown pelicans are more efficient foragers and have significantly higher feeding success rates than juveniles. Similar results have been published by Schnell et al. (1983) and are supported by this study.

Overall, foraging success rates favored adults at five feeding localities. When localities are examined individually, however, success rates were not significantly different at Humacao Lagoons, Culebra Island, and San Juan Bay.

Disagreement between the predicted outcome and observed feeding patterns at these localities might stem from differences in the length of observation periods in which they were recorded. In past studies, observations have been made for short periods of time (2 to 3 days) while food was concentrated and perhaps fish were more catchable. Observations in this study were made continuously for over a year, enabling me to detect variations in foraging success rates undetected in other studies.

Probable factors inducing variability were water turbidity and learning skills of juveniles. Anderson and Anderson (1976) suggested that pelicans are less dependent on non-turbid waters because they are not deep "plungers". However,

feeding success rates declined linearly with increased turbidity. Adults were more efficient than juveniles in relatively clear water and where prey species were more densely concentrated in schools near the surface, but age-related differences in foraging success were not clearly distinct in areas of higher water turbidity. Possibly, juveniles learned feeding skills rapidly by associating with adults, presumably their parents, and quickly became as efficient as adults in catching fish by the time they reached Puerto Rico. Orians (1969) conceded that learning might explain the lack of significance between age classes during certain periods of the year.

Future studies dealing with age-related differences in foraging success of brown pelicans should (1) monitor feeding rates of marked individuals by age class; it is possible that juveniles plunge-dive at higher frequencies to compensate for lower success rates, (2) follow individually marked pelicans throughout the day to assess diel variations in feeding success, (3) include areas of low to high turbidity to further evaluate this factor, (4) be conducted for annual periods to assess success rates of newly-fledged individuals and their improvement over time (e.g., comparisons of winter and summer rates in Puerto Rico).

Food and its characteristics in space and time influence feeding activities (Crook, 1965; Schoener, 1971; Krebs, 1974;

Erwin, 1978). High food predictability in San Juan Bay, Dorado and Humacao Lagoons probably reduced searching time leaving more time for prey pursuit (MacArthur and Pianka, 1966). Perhaps for this reason, individuals fed at different times, resulting in loose and poorly-synchronized aggregations as suggested for other species (Crook, 1965; Krebs, 1974).

Lower overall fish abundance coupled with rather uniform distribution were probably responsible for small group and solitary feeding activities in areas such as Parguera. Food in those areas was primarily found along the root systems of fringe and overwash mangroves. Uniformly distributed food was believed to be the causal factor of solitary foraging behavior in common terns and black skimmers (Erwin, 1977). Synchronized feeding activities and large feeding aggregations seemed to occur in the Greater Puerto Rican Bank only when large schools of fish appeared and were detected by feeding pelicans.

Food Habits

The broad distributional range of brown pelicans extending from tropical to warm (temperate) regions is partly due to their ability to forage as a generalist (Ainley, 1977; Anderson and Anderson, 1976). The diet of the eastern brown pelican was once thought to be comprised mostly of Atlantic menhaden (Brevoortia tyrannus), and shifts in nesting chronology were believed caused by shifts in availability of

menhaden (Palmer, 1962). Recent assessment of the eastern brown pelican nestling diet, however, suggests that the diet is more varied with menhaden accounting for only about 21% of the total. Moreover, there has not been a noticeable change in menhaden populations or seasonal differences in availability (Fogarty et al., 1981). This suggests that eastern brown pelicans are not obligate consumers and probably are able to adjust their nesting chronology to a period in which maximum young production is attained (Lack, 1954; Schreiber, 1980b).

In California, brown pelicans are nearly obligate consumers of the northern anchovy (Endraulis mordax) (Sunada et al., 1981). Breeding success is closely related to local abundance and availability of this species (Sunada et al., 1981; Anderson et al., 1982). Its predominance in the diet of pelicans (up to 92%) is probably due to population declines of Pacific sardines (Sardinops sagax) and Pacific (chub) mackerel (Scomber japonicus) caused by human overexploitation and density-independent physical factors impinging upon the fish community (Murphy, 1966; Anderson et al., 1980; Radovich, 1981; Cheldon, 1981).

The generalist tendencies of Caribbean brown pelicans in the Bank region are best exemplified by the high frequency of mixed-species regurgitations obtained from nestlings and the capability of adults and juveniles to feed on species such as

Tilapia when foraging in estuarine systems. A broad-based diet is undoubtedly advantageous to adult pelicans in meeting their daily and breeding nutritional demands. Similarly, it is advantageous to juveniles because they suffer high mortality rates during their first years of life (Henny, 1972) and exhibit deferred maturity which presumably is influenced by their inability to forage efficiently (Orians, 1969).

Many aquatic and marine avian species feed their young and themselves on what is available (Kushlan, 1978; Ainley and Sanger, 1979), and Caribbean brown pelicans are no exception. The composition of prey species is similar between Puerto Rico and the U.S. Virgin Islands. The slight differences observed were probably due to differences in fish community composition in mangroves versus more open coraline habitats and to variation in foraging preferences of individual pelicans. The age-class of prey species might have also influenced the diet composition of pelicans. Fish larvae and fry tend to move inshore to more productive and secure waters (Hewitt and Methot, 1982; Hewitt and Brewer, 1983).

Concern about the deleterious effects of commercial fishing on California brown pelicans has been reported (Anderson et al., 1980; Sunada et al., 1981; Anderson and Gress, 1983 and 1984). In the Greater Puerto Rican Bank, however, the food base of Caribbean brown pelicans is not commercially exploited (Caribbean Fishery Management Council,

1982). Food species of pelicans are caught and used by local fishermen as bait fish, but the fishermen's impact on fish stocks is probably negligible. Similarly, pelicans are not believed to adversely affect fish stocks (Anderson et al., 1982). Therefore, the pelican's food base in the Bank region is largely regulated by life history characteristics of the various fish species and density-independent environmental factors.

Nesting Biology

The factors controlling the onset and chronology of breeding activities of pelicans in a tropical environment are unknown (Schreiber, 1980b). Daylength and temperature exert a controlling role in avian breeding patterns in temperate zones (Immelmann, 1973; Murton and Westwood, 1977). In the Caribbean region, such environmental factors are very subtle and difficult to detect. The Puerto Rican Bank region is dominated by tropical maritime weather. Differences in daylength between summer and winter barely approach 2 hours. Similarly, temperatures are remarkably uniform seasonally and year-to-year at a given locality (Heatwole et al., 1981). It is possible, then, that an endogenous cycle in pelicans sensitive to subtle environmental cues plays a major role in synchronizing breeding activities. These include broadly rhythmic fluctuations of key environmental factors (Nelson, 1983).

Schreiber (1980b) has suggested that pelicans in Florida time their nesting period to avoid the hurricane season and other periods of major weather disturbances. However, initiation of most breeding activities in the Bank region occurs during the hurricane season (July 1 to November 30).

The availability of suitable nesting habitat also influences breeding activities and colony size (Schreiber and Schreiber, 1982; Nelson, 1983). In the Bank region, nesting habitat was readily available as suggested by the use of alternate nesting substrate within a colony site or different colony sites in different years. In western and southwestern Puerto Rico, colony size is probably limited by nesting habitat dimensions.

Ultimately, food probably determines pelican reproductive activities in this region. The regulatory function of food in marine birds has been stressed by Ashmole (1971) and Nelson (1977). Food undoubtedly influences the onset of reproduction and eventual nesting success of pelicans on the continent (Schreiber, 1979; Anderson et al., 1982). Nelson (1969) and Harris (1969) have documented the ability of tropical seabirds to respond to sudden changes of food availability, and it is likely that Caribbean brown pelicans are capable of detecting subtle changes in food abundance and availability.

Evolutionarily, consistently good food supplies during fall have probably synchronized breeding efforts leading to

higher fledging rates (Lack, 1966; Immelmann, 1973; Murton and Westwood, 1977; Anderson et al., 1982). Breeding efforts outside the observed peak nesting period (fall) resulted in lower reproductive success in the U.S. Virgin Islands and fewer nesting attempts at Conejo Cay, Vieques. Similar findings were reported by Schreiber (1979, 1980b) for continental populations.

Although lack of food data for the Puerto Rican Bank region precludes a quantitative analysis of food as a controlling factor of pelican breeding patterns and nesting success, it seems unescapable that environmental factors, as subtle as they might be, combine to enhance the food base of pelicans during fall. It is possible that increased runoffs in the hurricane season, which is the region's season of highest rainfall, and the break-up of the thermocline as tropical disturbances pass through the region, result in nutrient enrichment leading to greater food abundance. However, the extent to which rain runoffs regulate year-to-year fish biomass is probably limited. This is due to the irregularities of rainfall patterns, their intensity, and the resultant effects in the marine community which could include undesirable consequences such as red tides (Dr. Juan G. Gonzalez, Marine Biologist, University of Puerto Rico, Mayaguez, P.R., personal communication).

Anderson and Gress (1983) suggested that whatever controls

breeding efforts in California brown pelicans, it operates similarly in direction and intensity. With the possible exception of minor intercolony variations and relative stability in numbers of breeding pairs in Puerto Rican colonies, breeding colonies in the Greater Puerto Rican Bank region conformed with this view. Breeding efforts and nesting success were highest in 1980-81. If it is assumed that pelicans are a good indicator of food conditions and that fledging rates are significantly correlated with local patterns of food availability (Anderson et al., 1980; Anderson et al., 1982; Anderson and Gress, 1983), then 1980 must have been a period of relatively high food abundance. Apparently, these conditions did not prevail during the remainder of the study when fewer adults bred (e.g., 44% fewer in the U.S. Virgin Islands in 1982) and they had lower productivity rates (e.g., 60-67% lower in Puerto Rican colonies) during the fall.

Annual variations in colony sizes and seasonal synchrony are likely to be influenced by the amount of food (proximally related) and the numbers of pelicans that have met pre-breeding nutritional requirements (Schreiber, 1980b; Anderson and Gress, 1983; Nelson, 1983). Extended breeding seasons and larger-sized colonies in the eastern Puerto Rican Bank may be related to the broader undersea platform in that area (Heatwole et al., 1981). Conditions on the shallow platform east of Puerto Rico are well-suited for the development of

coraline communities (Velazco et al., 1985). Nutrient loads from oceanic currents and runoffs may remain available for longer periods of time, become incorporated into the food chain, and thereby support a larger food biomass. However, food is patchy in its distribution. Colony size and a better defined breeding pattern in southwestern and western Puerto Rico appear to be influenced by smaller nesting sites and lower overall food abundance.

Pelican production rates in the Puerto Rican Bank are difficult to interpret due to the lack of long-term data (6-8 years) (Schreiber, 1980a; Schreiber and Schreiber, 1983; Anderson and Gress, 1983). Henny (1972) estimated age-related mortality and recruitment rates needed to maintain a stable population. Schreiber (1979) challenged these estimates indicating that field data overwhelmingly show that "normal" nesting success rates for brown pelicans fluctuate around or slightly below 1.0 young fledged per nesting pair per year. Keeping in mind that such rates might not be applicable to Caribbean populations, it appears that brown pelicans in this part of their range were within "normal" productivity rates of a stable population, at least during peak breeding periods.

Anderson and Gress (1983) have suggested the use of maximum fledging rates attained by pelicans when food conditions are most suitable rather than using recruitment standards set by Henny (1972) to assess the reproductive

performance of pelicans. Maximum fledging rates for Caribbean pelicans during 1980 to 1983 were 5% to 25% higher than those of Florida and California populations, respectively (Schreiber, 1979; Anderson et al., 1982). These findings are encouraging. However, these data were collected over a relatively short time period and should be used with caution.

Habitat

Feeding habitat

Coastal feeding habitats were similar in having shallow waters and mixed bottoms of coraline formations and sand. In areas where the sand terrace and light penetration permitted, beds of Thalassia were common. In Puerto Rico, feeding habitat also included estuaries and brackish and freshwater impoundments. Main differences between Puerto Rico and the U.S. Virgin Islands were the predominance of mangroves in the former and coraline bottoms along the edges of offshore cays in the latter. It is difficult to clearly define why nutrient-rich waters associated with mangrove communities supported fewer and smaller colonies in Puerto Rico compared to the more open marine environment in the U.S. Virgin Islands. Possibly, as suggested in the previous section, the breadth of the eastern portion of the geological platform together with non-turbid waters and oceanic nutrient inputs does indeed support a higher food biomass. Certainly, breeding pelicans in the U.S. Virgin Islands remained in the

general area, reducing flying costs between food sources and nesting colony (Orians and Pearson, 1979). Perhaps, food sources in Puerto Rico, except for selected localities, are more widely and uniformly distributed precluding higher nesting densities.

Post-season movements, however, indicate that Puerto Rico is an important feeding area for maturing juveniles and post-breeding adults. This role, though, could be changed by the gradual deterioration of many coraline communities due to sedimentation from runoff (Velazco et al., 1985). Mangrove systems are also subject to stress from continued human encroachment and disturbance (Cintron and Schaeffer-Novelli, 1983). Such problems are not as critical in the U.S. Virgin Islands due to the reduced number of permanent streams on the islands and lesser importance of mangrove tracts in supporting the food base of pelicans. Continued deterioration of both mangrove and coraline communities in Puerto Rico could have long-term consequences affecting movement patterns and distribution of pelicans in the Bank.

Roosting and nesting habitat

Assuming present patterns of habitat use are normal, the availability of roosting and nesting sites are not limiting pelican populations in the Greater Puerto Rican Bank. In the U.S. Virgin Islands, where the breeding population is

centered, colony sites were numerous, large in size, and their nesting substrate was not disturbed except by the pelicans themselves. Alternate cays with similar vegetation type were available in the general vicinity as well. Similarly, in Puerto Rico, where 91% of roosting and nesting occurs on mangrove vegetation, unoccupied habitat was readily available to pelicans.

Schreiber and Schreiber (1982) stressed the need to protect not only nesting sites but also loafing and roosting sites because these sites could eventually become nesting sites. In addition, these habitat types offer an undisturbed area where maintenance activities as well as resting and sleeping occur. In the Greater Puerto Rican Bank region, rocky edges surrounding cays and outcrops of coral rubble along the coast probably serve a similar role as sand bars in Florida. Schreiber and Schreiber (1982) suggested that sand bars are important to juveniles lacking sufficient skills to land on trees. Traditional sites deserve special protection because they tend to be re-used for many years.

Human encroachment is the major threat to essential pelican habitat in Puerto Rico. In the U.S. Virgin Islands, roosting and nesting habitat occurred on rugged, relatively inaccessible cays where human encroachment poses little threat to their continued use. In contrast, in Puerto Rico roosting and nesting habitat is usually close to human habitation or to

a high activity area.

Wadsworth (1969) estimated that only 25% of the original mangrove acreage in Puerto Rico remains at present. Close to 91% of all roosting and nesting habitat utilized in Puerto Rico were fringe and overwash mangroves. Fringe mangroves are particularly important to the feeding ecology of pelicans because they provide nutrient inputs and cover for its associated marine community, including food fishes. Both mangrove types are very sensitive to human-created stress such as deforestation, filling and extractions in the salt flats, sedimentation, and oil spills (Cintron and Schaeffer-Novelli, 1983). Overwash mangrove islets should receive maximum protection because their growth rates and regeneration times are very slow. Aerial photographs of colony sites at Montalva Bay have not shown appreciable growth over the last 20 years. Slow growth patterns suggest that existing mangrove islets constitute all the habitat of this kind that will be available until well into the next century (Gilberto Cintron, Marine Biologist, Department of Natural Resources, Puerta de Tierra, P.R., personal communication).

Recently, Hingtgen and Mulholland (1983) suggested that suitable pelican habitat could be identified by evaluating vegetational characteristics, size of island, distance to mainland, distance to nearest human disturbance, and availability of sand bars. In Puerto Rico, 4 criteria should

be assessed when prioritizing potentially useful mangrove sites. These are (1) structural characteristics of trees, (2) utilization patterns in the general area surrounding the site in question, (3) historical use of the site, (4) level of human disturbance.

Structural suitability can be assessed by using the linear classification rule (discriminant function analysis) presented in this study based on structural variables of roosting and nesting sites of mangrove vegetation. A site classified as "used" means that its structural characteristics are similar to those found in used sites. It does not mean that the site in question will be used by pelicans. Pelicans probably select specific sites using many variables in addition to simple structural variables.

All feeding, roosting, and nesting areas in Puerto Rico were classified according to intensity of use. Maximum efforts should be made to protect sites that were classified as "used" if they occur within traditionally-used areas. Efforts should also be made to determine the historical use of a given site or area. The pelican's tendency to use former nesting or roosting sites increases the possibility of their use in the future.

Human disturbance is a critical factor in assessing suitability of roosting and nesting habitat (Schreiber, 1979; Schreiber and Schreiber, 1982). Precise figures of

undesirable levels of human disturbance are difficult to assess a priori. Determining a threshold level is all but impossible given the widespread habituation to various degrees of human disturbance in Puerto Rico, e.g., Conejo Cay (nesting) and Dorado Lagoons (foraging). The pelicans themselves are the best indicators as they will select loafing and roosting sites with tolerable levels of disturbance before they use a site for nesting (Schreiber and Schreiber, 1982) Nonetheless, the rule should be to protect those sites furthest away from human habitation and activity, particularly if the above-mentioned criteria are met.

Environmental Concerns and Disease

Chlorinated pesticides were the major cause of widespread reproductive failure in continental populations (Schreiber, 1980a). In recent years, higher reproductive rates have been correlated with decreasing levels of deleterious pesticides (Mendenhall and Prouty, 1978; Anderson and Gress, 1983).

Historically, low organochlorine and heavy metal residue levels in biological samples in the Greater Puerto Rican Bank (Reimold, 1975) suggest that these contaminants were not affecting Caribbean pelicans when continental populations suffered highest reproductive failures. Analysis of egg samples during this study indicate that residue levels of impacting chlorinated pesticides and heavy metals were not affecting Caribbean brown pelicans at present either.

Eggshell thickness and thickness index values were similar to pre-1947 values (Anderson and Hickey, 1970) indicating that pesticides probably never affected Caribbean brown pelican populations.

The 1982 die-offs, amounting to about 7% of that year's mean population in Puerto Rico, represented the only widespread mortality that can be attributed to contaminants and disease in the Greater Puerto Rican Bank. Organophosphates were implicated in the Dorado Lagoon die-off whereas botulism was the probable cause of death at Humacao. Both Humacao and Dorado lagoons consistently attracted high numbers of pelicans, especially juveniles. Re-occurrence of die-offs in any of these areas will hit juveniles hardest. Die-offs, particularly at sites where pelicans aggregate (e.g., San Juan Bay), could have a substantial impact on future breeding populations if allowed to recur unchecked. Steps should be taken to reduce the probability of pesticide poisoning and other pollution related causes of mortality.

Pelicans in the Greater Puerto Rican Bank Region

Two events stand out as essential in order to comprehend the population dynamics of pelicans in the Bank region. These are the timing and success of the breeding cycle and the pronounced seasonal fluctuations in pelican numbers in Puerto Rico.

Of the factors impinging upon the population, food is the

single most influential. I suggest that because the Greater Puerto Rican Bank region is influenced by tropical maritime weather, factors affecting food availability operate at low intensity levels with alternating periods of abundance and scarcity. This view is supported by the unpredictable nature and intensity of oceanographic factors (e.g., marine currents) affecting this region.

Timing of the pelican breeding cycle is probably regulated by their ability to proximally detect changes of food availability. The fall season seems to provide the highest food availability as peak nesting efforts concentrate during this period. However, while the latter is true, starting dates and peak nesting activity can vary year to year. Variability is probably due to differential ability of adults to meet pre-breeding requirements and to join the breeding population, social factors, and as mentioned above, detect favorable feeding conditions (Schreiber, 1980b; Nelson, 1983).

Lack (1966) suggested that parents will raise as many young as food resources permit. Notwithstanding the fact that pelicans almost always have a clutch of 3 (probably related to inshore foraging patterns), Caribbean brown pelicans conformed with this view. Fledging rates are closely related to local patterns of food availability (Anderson et al., 1980; Anderson et al., 1982). These findings lead me to suggest that in 1980, food availability was unusually high, and pelicans

maximized their reproductive output. The 1980 fledging rates probably represent the "ceiling level" or maximum fledging rate as defined by Anderson and Gress (1983).

Breeding efforts and fledging rates in subsequent years declined considerably, suggesting that food was relatively scarce. The unpredictable nature of food level oscillations will undoubtedly result in long-term fluctuating fledging rates as described by Schreiber (1979).

The second major event in Caribbean brown pelican population dynamics is the migratory movements of juveniles and post-breeding adults to Puerto Rico. Individuals of both age classes converge in Puerto Rico, remain there until they reach maturation (juveniles) or attain breeding conditions (adults), and then return to traditional breeding sites.

This annual migratory pattern leads me to suggest that Caribbean brown pelicans in the Greater Puerto Rican Bank region are a single, intermixing population. The nucleus of the breeding population is centered in the U.S. Virgin Islands. Puerto Rico serves as an important foraging area for maturing juveniles and for adults to meet pre-breeding nutritional requirements including the possible acquisition of body nutrient reserves.

Nelson (1977, 1978) suggested that most seabird populations are regulated by factors other than themselves. This appears to be the case for brown pelicans in the Greater

Puerto Rican Bank region. None of the impacting factors on continental populations were adversely affecting or were detected in this region. Two 1982 die-offs represented the only widespread mortality events that occurred during this study. Regionally, climatological factors or nesting site availability are not limiting brown pelicans. Apparently, low level food availability and its subtle and unpredictable fluctuations is the overriding regulatory factor of brown pelican numbers in the Greater Puerto Rican Bank.

STATUS ASSESSMENT

During the 3-year study, the brown pelican population in the Greater Puerto Rican Bank region was healthy and the overall reproductive rate was within the range of values believed necessary to maintain a stable population over a long term. However, the population was experiencing a downward trend both in numbers of breeding pairs and number of young produced, particularly in the U.S. Virgin Islands where most pelicans bred. It is too soon to tell whether these declines are long term or just part of a natural short-term cycle. Factors which caused endangerment in continental populations were not affecting pelicans in this region in any appreciable extent. Environmental contaminants or oil spills did not present an immediate threat to brown pelicans, but these hazards should be continually monitored and controlled. Unusual pelican die-offs occurred in 1982 at two isolated localities and were unrelated events that did not recur.

Meaningful data on population numbers, reproductive rates, and epizootics for Caribbean brown pelicans should be compiled for a period of 6 to 8 years. The decision to remove the eastern brown pelican from the endangered species list came about only after a strong resurgence of population numbers coupled with decreasing levels of environmental contaminants monitored for over 10 years. Therefore, I propose that the endangered status of the Caribbean brown

pelican maintained for another 5 years, commencing in 1985 while additional data are obtained.

MANAGEMENT RECOMMENDATIONS

General Objective

The general recovery objective for the Caribbean brown pelican of the Greater Puerto Rican Bank region is to achieve and maintain a healthy population that would lead to its removal from the list of endangered species. A sustainable population is defined as a running 5-year mean population level of 2,300 individuals counted during January censuses in the coastal waters of Puerto Rico and the U.S. Virgin Islands. The goal also includes the maintenance of a running 5-year average peak of 350 breeding pairs for the region. Because there is insufficient data to evaluate long-term trends, it is recommended that endangered status of the brown pelican in the Region be maintained at least until 1990.

Recovery Actions Taken to Date

The Caribbean brown pelican was included in the list of protected species by the Commonwealth of Puerto Rico in 1973 and protected by law 70 in 1976 which protects all wildlife in Puerto Rico.

Specific Recommendations

The following specific recommendations are suggested as minimal measures for completing the evaluation of the status of the brown pelican in the Puerto Rican Bank Region and

ensuring that a viable population of pelicans is maintained and conserved.

1. Maintain the endangered status of the brown pelican until 1990. Brown pelicans are a long-lived species. Meaningful data on population trends can be obtained only through long-term monitoring (at least 8 - 10 years). Baseline data for the Greater Puerto Rican Bank region is available for 3 years (1980-1983). Monitoring should be conducted through 1990 at which time the status of the population can be reassessed.

2. Monitor population numbers using aerial censuses conducted throughout the region annually in January. Virtually the entire post-breeding population of the region can be counted except in areas having restricted air space. These surveys will also provide information on reproductive output if care is taken too make separate counts of adults and juveniles.

3. Conduct monthly boat counts each year from August to January to obtain age-ratio data at Humacao Lagoons and San Juan Bay. Both of these areas consistently attract sizable numbers of adults and young of the year.

4. Estimate fall breeding efforts by conducting monthly counts of active nests at all breeding colonies during September, October, and November. Schreiber and Schreiber

(1983) have suggested that nest counts made at the peak of the nesting season, coupled with age-ratio data, will provide an adequate index of productivity. However, because of high annual variation in the timing of breeding seasons in Puerto Rico, it is impossible to predict with certainty when the peak will occur within this 3-month period. Hence, a minimum of three counts should be conducted.

5. Monitor sites of important aggregations of pelicans for possible disease outbreaks or die-offs from environmental contaminants. These sites should include San Juan Bay, Dorado, and Humacao where pelicans are known to concentrate to feed. Die-offs have been documented recently at Dorado (probable organophosphate poisoning) and at Humacao (botulism). A detailed protocol should be agreed on in advance by all responsible agencies (chiefly, the U.S. Fish and Wildlife Service (Ecological Services), the Puerto Rico Department of Natural Resources, and the U.S. Virgin Islands, Division of Fish and Wildlife for handling the collection of samples for toxicological and pathological diagnosis and assessment.

6. Re-examine organochlorine residues in brown pelican eggs in 1988-89. One-third of the eggs collected in the fall of 1982 at the Montalva Bay colony had elevated levels of DDE.

7. Continue to protect coastal marine communities and associated mangrove systems by complying with management and conservation recommendations outlined by the Puerto Rico Department of Natural Resources (Velazco et al., 1985; Cintron and Schaeffer-Novelli, 1983). Efforts to reduce and minimize pollution in these ecosystems will ultimately benefit pelicans through enhancement of catchable fish populations.

8. Protect present and potential breeding and roosting sites. Breeding and roosting in the U.S. Virgin Islands occurs on currently protected sites or on remote inaccessible cays where the likelihood of human encroachment is small. In Puerto Rico, however, almost all major breeding and roosting sites are potentially subject to further human encroachment. During 1980-1983, 91% of all roosting and nesting occurred on mangroves. Human encroachment has reduced mangrove area on the island to about 25% of its historical expanse. Potential mangrove sites can be evaluated for their possible use by pelicans using a classification rule based on structural values developed

in this study. The rule provides criteria for prioritizing potential roosting and nesting sites.

9. Develop an environmental education program. A stronger effort is needed to inform the general public of the region on the importance of protecting pelicans and their traditional breeding, roosting, and feeding sites.

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APPENDIX: RAW AND PROCESSED NUMERICAL DATA (TABLES 1-12)

APPENDIX, TABLE 1. Quarterly censuses of brown pelicans by date in Puerto Rico and adjacent islands including aerial counts and counts made on restricted areas by boat (1980-83)

Quarter	Count	Mean/Year
Fall, 1980	1,466	
Winter, 1980	2,423	1,944/1980
Spring, 1981	2,140	
Summer, 1981	1,851	
Fall, 1981	1,996	2,052/1981
Winter, 1981	2,224	
Spring, 1982	2,088	
Summer, 1982	1,778	1,983/1982
Fall, 1982	1,847	
Winter, 1982	2,221	

APPENDIX, TABLE 2. A list of pelicans recovered in Puerto Rico, and the United States Virgin Islands (1980-83)

Bird	Banded	Recovered	Location	Coastal Zone
A06	10-27-80	09-02-82	Tortuguero	Northcentral
A07	11-25-80	06-06-81	Humacao	Southeast
A15	01-08-81	04-28-81	Dorado	Northcentral
A16	01-08-81	02- -81	Torrecillas	Northeastern
A19	01-08-81	02-15-81	Mayaguez	Western
A23	01-08-81	04-28-81	Dorado	Northcentral
A34	10-24-81	11-25-81	Arecibo	Northcentral
A48	01-18-81	01-11-83	Isabela	Northwestern
F04	01-13-80	04- -81	Humacao	Southeast
F07	01-13-81	02-14-81	Humacao	Southeast
F10	01-13-81	02- -81	Vieques	Offshore Island
F31	01-27-81	12-17-81	Vieques	Offshore Island
F36	10-27-81	03-18-82	Vieques	Offshore Island
F41	12-02-81	04-15-82	Vega Baja	Northcentral
F43	12-02-81	01-24-82	Ponce	Southcentral
F55	01-14-82	03-18-82	San Juan Bay	Northeastern
F56	01-14-82	11-15-82	Humacao	Southeastern
F57	01-14-82	03-07-82	Parguera	Southwestern
F58	01-14-82	02-19-82	Conejo Cay	Offshore Island
C05	07-13-82	12-27-82	San Juan Bay	Northeastern
C16	07-14-82	08-03-83	San Juan Bay	Northeastern
E02	01-22-81	11-01-82	Humacao	Southeastern
E18	01-22-81	03-21-81	Hatillo	Northcentral
E20	01-22-81	03-19-81	Dorado	Northcentral
E22	02-13-81	06-05-81	San Juan Bay	Northeastern
E25	03-13-81	05-26-81	St. Thomas	U.S.V.I.
E55	10-09-80	06-04-81	Arecibo	Northcentral
E79	01-09-81	03-22-81	Culebra	Offshore Island
E87	01-23-81	04-09-82	Dorado	Northcentral

APPENDIX, TABLE 3. Structural values from used and non-used mangrove sites in Puerto Rico and adjacent islands

Site	DEN [a]	DBH [a]	HT [a]	DE [a]	Use
Guayanilla	2093	7.93	3.27	15.81	Not used
"	3156	9.25	5.50	17.05	Not used
"	4162	9.47	4.70	8.34	Not used
"	2994	15.26	7.16	8.78	Used
"	2467	15.98	7.05	10.62	Used
"	462	21.38	8.50	0.00	Used
"	688	20.04	8.40	2.28	Used
Cabo Rojo	1873	11.89	5.75	15.24	Not used
"	4383	11.64	5.94	9.14	Not used
"	2666	12.43	5.67	13.71	Not Used
"	7928	10.04	6.43	5.00	Used
"	4313	10.82	7.96	5.00	Used
"	3525	9.71	6.80	5.00	Used
"	7696	8.78	7.80	5.00	Used
Ceiba	1056	13.62	5.69	4.10	Not used
"	1080	13.46	5.32	6.55	Not used
"	2107	11.50	4.70	9.49	Not used
"	2734	10.59	5.36	10.15	Not used
"	499	19.01	6.53	9.30	Not used
Parguera	5026	12.00	4.75	5.05	Not used
"	8773	5.46	3.58	10.50	Not used
"	5669	10.80	5.90	12.01	Not used
"	7754	8.34	5.61	6.37	Used
"	1256	18.29	8.91	10.12	Used
"	8018	9.25	4.56	5.70	Used
"	5026	8.95	4.75	5.05	Used
"	5897	8.94	5.02	10.80	Used
"	550	16.27	5.50	3.88	Used
"	867	15.99	6.26	6.00	Used
"	1450	10.62	5.47	3.85	Used
"	2896	9.81	6.50	7.00	Used
"	974	18.42	5.80	3.10	Used
"	2292	14.66	5.95	8.75	Used
"	1996	13.08	6.30	7.75	Used

[a] DEN=density; DBH=diameter at breast height; HT=height; DE=distance to edge.

APPENDIX, TABLE 3 (cont.).

Site	DEN [a]	DBH [a]	HT [a]	DE [a]	Use
Jobos Bay	3864	10.39	7.90	6.00	Not used
"	3864	9.56	5.60	6.00	Not used
"	7064	7.53	5.90	5.00	Not used
"	6556	7.59	5.30	5.00	Not used
"	5221	7.29	5.50	5.00	Not used
"	3947	8.74	4.80	5.00	Not used
"	11165	6.13	4.20	5.00	Not used
"	6749	7.51	5.40	5.00	Not used
"	7193	9.57	4.30	3.00	Not used
"	1746	16.07	9.32	5.50	Used
"	5406	10.04	5.69	5.50	Used
Vieques	2567	15.13	5.80	6.00	Not used
"	2881	14.97	5.14	6.00	Not used
Culebra	14807	7.34	3.99	6.27	Not used
"	10679	5.78	2.92	4.95	Not used
"	6897	8.62	5.23	7.36	Not used
"	7974	6.41	3.10	5.34	Not used
"	11395	7.68	5.00	7.09	Not used
"	7788	7.14	4.02	7.28	Not used
"	8156	7.01	2.91	4.32	Not used
"	4462	8.86	3.95	9.38	Not used
"	2825	11.93	7.59	5.44	Used
"	959	18.49	8.36	7.95	Used
"	4128	10.03	6.02	7.55	Used
Torrecillas	2918	13.35	4.77	6.12	Used
"	977	13.27	4.28	5.99	Used
"	882	16.81	5.62	4.42	Used
"	1125	17.12	7.87	7.66	Used
Guanica	1528	20.20	7.71	6.78	Used
"	424	19.70	7.27	6.93	Used
San Juan Bay	7767	9.52	7.26	4.89	Used
"	6530	6.96	5.57	6.33	Used
"	12718	5.83	5.54	7.13	Used
"	5541	6.57	4.81	7.30	Used

APPENDIX, TABLE 4. Pooled variance-covariance matrix constructed using variables measured on used and non-used sites of all mangrove species combined and of red mangrove in Puerto Rico and adjacent islands

Pooled variance-covariance matrix (d.f.=66)

Variable[a]	DEN	DBH	HT	DE
den	10147392.3353	-9316.7440	-1593.6704	-1836.3305
dbh	-9316.7440	14.7577	2.6602	0.0784
ht	-1593.6704	2.6602	1.5256	0.0832
de	-1836.3305	0.0784	0.0832	8.8781

Pooled variance-covariance matrix (d.f.=47)

Variable[a]	DEN	DBH	HT	DE
den	10106653.2021	-9165.1908	-1942.0076	-1720.0731
dbh	-9165.1908	15.2454	3.0911	-0.9593
ht	-1942.0076	3.0911	1.6235	0.1502
de	-1720.0731	0.9593	0.1502	10.1602

[a] den=density; dbh=diameter at breast height; ht=height; de=distance to edge.

APPENDIX, TABLE 5. ANOVA tables for catches of selected species of fishes at San Juan Bay, Dorado, and Humacao, Puerto Rico (1980-83)

DEPENDENT VARIABLE: Mean catches of Cetengraulis edentulus at San Juan Bay.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	119	994.2373	8.3549	6.93	0.0001	0.77
Error	240	289.4920				
Corrected Total	359	1283.7292				

Source	DF	Type III SS	F	P>F
Month	8	190.8059	6.49	0.0001
Set	1	95.0822	25.89	0.0001
Net (Set)	4	6.6744	0.45	0.7687
Month*Net*Set	40	146.9134		
Time	1	1.4785	0.16	0.6906
Set*Time	1	7.6837	0.84	0.3665
Net*Time (Set)	4	9.7169	0.26	0.8988
Month*Set*Net*Time	36	330.6349		
Panel	2	145.1795	60.18	0.0001
Set*Panel	2	5.5345	2.29	0.1031
Net*Panel (Set)	8	4.3616	0.45	0.8886
Time*Panel	2	0.5991	0.25	0.7803
Set*Time*Panel	2	0.6396	0.27	0.7673
Net*Time*Panel (Set)	8	2.6550		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Harengula clupeola at San Juan Bay.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	119	220.3341	1.8515	3.11	0.0001	0.61
Error	240	110.8351	0.4618			
Corrected Total	359	331.1693				

Source	DF	Type III SS	F	P>F
Month	8	38.3955	4.08	0.0013
Set	1	7.3612	6.25	0.0166
Net (Set)	4	1.5657	0.33	0.8545
Month*Set*Net	40	47.0961		
Time	1	0.7367	0.31	0.5784
Set*Time	1	13.0902	5.59	0.0236
Net*Time (Set)	4	0.6655	0.07	0.9904
Month*Set*Net*Time	36	84.3163		
Panel	2	8.8763	9.61	0.0001
Set*Panel	2	1.6428	1.78	0.1711
Net*Panel (Set)	8	4.0157	1.09	0.3729
Time*Panel	2	2.1338	2.31	0.1014
Set*Time*Panel	2	0.8066	0.87	0.4189
Net*Time*Panel (Set)	8	1.9459		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Opisthonema oglinum at San Juan Bay.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	119	103.4607	0.8694	3.11	0.0001	0.61
Error	240	67.0913	0.2795			
Corrected Total	359	170.5521				

Source	DF	Type III SS	F	P>F
Month	8	32.0307	5.85	0.0001
Set	1	6.9416	10.08	0.0029
Net (Set)	4	0.1597	0.06	0.9935
Month*Set*Net	40	27.5563		
Time	1	1.2209	3.51	0.0693
Set*Time	1	1.6105	4.63	0.0383
Net*Time (Set)	4	0.9901	0.71	0.5898
Month*Set*Net*Time	36	12.5339		
Panel	2	18.6275	33.32	0.0001
Set*Panel	2	4.3820	7.84	0.0005
Net*Panel (Set)	8	0.5086	0.23	0.9856
Time*Panel	2	1.5210	2.72	0.0679
Set*Time*Panel	2	1.6858	3.02	0.0509
Net*Time*Panel (Set)	8	0.1213		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Tilapia mossambica at Mata Redonda Lagoon, Dorado.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	38	77.9038	2.0501	3.08	0.0001	0.51
Error	114	75.9593	0.6663			
Corrected Total	152	153.8631				

Source	DF	Type III SS	F	P>F
Month	4	31.7670	22.93	0.0002
Net	2	1.4874	2.15	0.1792
Month*Net	8	2.7703		
Time	1	0.5816	1.47	0.2557
Net*Time	2	0.0272	0.03	0.9663
Month*Net*Time	9	3.5527		
Panel	2	31.3766	23.55	0.0001
Net*Panel	4	2.6346	0.99	0.4168
Time*Panel	2	1.5869	1.19	0.3077
Net*Time*Panel	4	2.4504		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE; Mean catches of Tilapia mossambica at Cerromar pond, Dorado.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	35	59.8855	1.7110	2.23	0.0059	0.63
Error	45	34.5954	0.7687			
Corrected Total	80	94.4809				

Source	DF	Type III SS	F	P>F
Month	3	8.0235	4.16	0.0652
Net	2	0.0015	0.00	0.9988
Month*Net	6	3.8607		
Time	1	21.1216	19.10	0.0018
Net*Time	1	1.3236	0.60	0.5701
Month*Time*Net	9	9.9509		
Panel	1	9.0554	5.89	0.0053
Net*Panel	4	2.0356	0.66	0.6217
Time*Panel	1	0.6477	0.42	0.6588
Net*Time*Panel	4	5.3587		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Lepomis spp. at Cerromar pond, Dorado.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	35	38.8168	1.1090	3.16	0.0002	0.71
Error	45	15.7717	0.3505			
Corrected Total	80	54.5885				

Source	DF	Type III SS	F	P>F
Month	3	3.2292	3.36	0.0963
Net	2	0.0409	0.06	0.9388
Month*Net	6	1.9222		
Time	1	2.3055	4.03	0.0756
Net*Time	2	0.1120	0.10	0.9077
Month*Net*Time	9	5.1487		
Panel	2	20.4018	29.11	0.0001
Net*Panel	4	0.2529	0.18	0.9474
Time*Panel	2	1.7991	2.57	0.0880
Net*Time*Panel	4	1.5331		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Tilapia mossambica at Mandri Lagoons, Humacao.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	83	48.6843	0.5865	4.09	0.0001	0.78
Error	96	13.7678	0.1434			
Corrected Total	179	62.4521				

Source	DF	Type III SS	F	P>F
Month	4	14.0527	29.36	0.0001
Set	1	0.4662	3.87	0.0633
Net (Set)	4	0.3501	0.73	0.5811
Month*Set*Net	20	2.3931		
Time	1	8.7125	15.86	0.0006
Set*Time	1	1.0155	1.85	0.1866
Net*Time (Set)	4	0.3336	0.15	0.9604
Month*Set*Net*Time	24	13.1865		
Panel	2	4.3899	15.30	0.0001
Set*Panel	2	0.1239	0.43	0.6505
Net*Panel (Set)	8	0.6336	0.55	0.8142
Time*Panel	2	2.1806	7.60	0.0009
Set*Time*Panel	2	0.1912	0.67	0.5159
Net*Time*Panel (Set)	8	0.6585		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Anchovia clupeoides at Mandri Lagoons, Humacao.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	83	96.8989	1.1674	2.26	0.0001	0.66
Error	96	49.6319	0.5169			
Corrected Total	179	149.5308				

Source	DF	Type III SS	F	P>F
Month	4	13.9162	4.34	0.0116
Set	1	3.1720	3.90	0.0622
Net (Set)	4	1.6667	0.51	0.7273
Month*Set*Net	20	16.2626		
Time	1	0.0151	0.01	0.9127
Set*Time	1	3.4255	2.78	0.1083
Net*Time (Set)	4	1.7740	0.36	0.8343
Month*Set*Net*Time	24	29.5393		
Panel	2	14.5569	14.08	0.0001
Set*Panel	2	2.3206	2.24	0.1115
Net*Panel (Set)	8	3.7206	0.90	0.5202
Time*Panel	2	1.4326	1.39	0.2552
Set*Time*Panel	2	1.2952	0.29	0.7523
Net*Time*Panel (Set)	8	4.8013		

APPENDIX, TABLE 5 (cont.).

DEPENDENT VARIABLE: Mean catches of Tilapia mossambica at Santa Teresa Lagoon, Humacao.

Source	DF	Sum of Squares	Mean Square	F	P>F	R^2
Model	65	110.8621	1.7056	8.44	0.0001	0.90
Error	60	12.1298	0.2022			
Corrected Total	125	122.9919				

Source	DF	Type III SS	F	P>F
Month	4	68.2872	44.34	0.0001
Set	1	0.4055	1.05	0.3192
Net (Set)	4	0.1995	0.13	0.9695
Month*Set*Net	17	6.5429		
Time	1	0.0218	0.07	0.8001
Set*Time	1	0.0592	0.19	0.6771
Net*Time (Set)	4	1.0684	0.83	0.5361
Month*Set*Net*Time	9	2.8796		
Panel	2	4.4708	11.06	0.0001
Set*Panel	2	0.0543	0.13	0.8747
Net*Panel (Set)	8	3.0872	1.91	0.0752
Time*Panel	2	0.6854	1.70	0.1922
Set*Time*Panel	2	0.3660	0.91	0.4099
Net*Time*Panel (Set)	8	2.0756		

APPENDIX, TABLE 6. Number of active nests observed at irregular intervals at Dutch Cap and Congo Cays, U.S. Virgin Islands, 1980-83

Date	Dutch Cap	Congo Cay
8-80	no visit	57
9-80	195	86
3-81	no visit	32
6-81	31	no visit
8-81	19	6
2-82	no visit	44
4-82	28	4
7-82	17	0
10-82	116	95
4-83	68	0

APPENDIX, TABLE 7. Wet weight residue levels (ppm) for Mercury (Hg), Lead (Pb), DDE, DDD, PCB, and Dieldrin in brown pelican eggs collected at Dutch Cap Cay, Montalva Bay, and Conejo Cay, 1982

Site	Hg	Pb	DDE	DDD	PCB	Dieldrin
Dutch Cap Cay	0.145	TR[a]	0.76	0.005	1.66	0.005
(U.S.V.I)	0.128	"	0.121	0.009	1.93	0.035
	0.218	"	0.154	0.021	2.97	0.021
	0.682	"	0.253	0.046	5.61	0.054
	0.270	"	0.018	0.005	0.286	0.005
	0.319	"	0.199	0.027	3.96	0.018
	0.129	"	0.103	0.006	0.220	0.027
	0.290	"	0.073	0.037	1.33	0.018
	0.837	"	0.271	0.057	5.29	0.057
	0.193	"	0.018	0.005	0.280	0.005
	0.256	"	0.125	0.018	0.331	0.005
	0.176	"	0.008	0.005	0.276	0.005
	0.164	"	0.059	0.005	1.11	0.045
	0.197	"	0.070	0.005	1.49	0.005
	0.245	"	0.132	0.008	2.39	0.008
	0.165	"	0.005	0.005	0.106	0.005
Montalva Bay	0.145	"	3.460	0.027	53.590	0.109
(Puerto Rico)	0.241	"	4.160	0.037	69.630	0.130
	0.276	"	0.160	0.022	0.356	0.005
	0.102	"	0.131	0.022	1.520	0.007
	0.165	"	0.113	0.017	2.300	0.005
	0.246	"	1.260	0.095	16.110	0.199
	0.151	"	3.870	0.009	94.220	0.005
	0.163	"	0.106	0.021	0.821	0.078
	0.228	"	1.06	0.038	19.44	0.057
Conejo Cay	0.215	"	0.32	0.008	0.353	0.005

[a] TR=traces.

APPENDIX, TABLE 8. Mean eggshell thickness and thickness index of brown pelican eggs collected at Dutch Cap Cay, Montalva Bay, and Conejo Cay colonies (1982)

	Mean[a] Thickness[b]	Thickness Index
Dutch Cap Cay	0.468	2.41
	0.533	2.41
	0.498	2.64
	0.487	2.31
	0.519	2.44
	0.533	2.46
	0.513	2.27
	0.563	2.18
	0.525	2.45
	0.394	2.12
	0.495	2.43
	0.457	2.30
	0.448	2.30
	0.544	2.34
	0.513	2.51
	0.531	2.46
Montalva Bay	0.458	2.14
	0.483	2.37
	0.499	2.44
	0.538	2.27
	0.538	2.14
	0.532	2.47
	0.508	2.36
	0.455	2.04
	0.565	3.06
Conejo Cay	0.429	2.07
	0.407	2.08

[a] Mean of three measurements at the equator.

[b] mm.

APPENDIX, TABLE 9. Numbers of pelicans collected at Dorado Lagoon (Mata Redonda) during a die-off from February through August 1982

Date	Adults	Juveniles
February 2	0	1
March 3	0	2
March 19	1	3
March 30	2	37
April 2	0	14
April 9	1	32
April 12	1	5
April 13	1	2
April 19	0	7
June 29	1	3
July 1	1	3
July 6	1	2
July 19	0	3
July 26	0	3
August 8	0	1

APPENDIX, TABLE 10. Water quality analyses of 4 samples collected at Dorado Lagoon (Mata Redonda) Dorado on April 1, 1982. Analyses were conducted by Puerto Rico Department of Natural Resources Analytical Laboratory

Total Coliform colonies/100 ml	Fecal Coliforms	Fecal Streps	PH
200,000	80	570	8.75
350,000	80	180	8.67
100,000	700	100	9.07
720,000	840	76	9.25

BOD (mg/l)	DO (mg/l)	Arsenate (ppm)	Lead (ppm)
0.58	7.76	0.054	0.028
0.20	8.09	0.046	0.014
0.58	19.15	0.003	0.018
0.39	19.20	0.004	0.020

APPENDIX, TABLE 11. Toxicological analyses of water and fish samples conducted by Puerto Rico Department of Agriculture, Analytical Laboratory (Dorado), 1982

Contaminant	Residues[a]
Diazinon	Not detected
Malathion	"
Toxaphene	"
Mocap	"
Arsenic residues	"

[a] Detection threshold of 0.01 ppm using GC-ECD.

APPENDIX, TABLE 12. Organochlorine residues (ppm) in brains of three brown pelicans from Dorado, Mata Redonda Lagoon, April 1, 1982. Residues are reported on a wet-weight basis. Lower limits of detection were 0.1 ppm for organochlorine and 0.5 ppm for PCBs. Analysis conducted by U.S. Fish and Wildlife Service, Putuxent Wildlife Research Center, Laurel, Maryland

Compound	1	2	3
p,p'-DDE	ND[a]	ND	0.99
p,p'-DDD	"	"	ND
p,p'-DDT	"	"	"
Dieldrin	2.0	0.80	0.28
Heptachlor epoxide	ND	ND	ND
Oxychlordane	"	"	"
cis-Chlordane	0.14	"	0.24
trans-Nonachlor	0.16	"	0.20
cis-Nonachlor	0.19	"	0.19
Endrin	ND	"	ND
Toxaphene	"	"	"
PCBs	"	"	11.00

[a] ND=none detected.